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CELL MODULE ASSEMBLIES AND METHODS OF MANUFACTURING CELL MODULE ASSEMBLIES

Abstract

A cell module assembly includes a first frame having a first plurality of pockets, a second frame spaced apart from the first frame and having a second plurality of pockets, a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame by a first curable adhesive, and a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame by a second curable adhesive. Each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/983,190, filed on Nov. 8, 2022, which is continuation of U.S. patent application Ser. No. 17/428,360, filed on Aug. 4, 2021, which a National Stage Entry of International Application No. PCT/US2020/016523, filed Feb. 4, 2020, which claims the benefit of and priority to U.S. Provisional Application No. 62/801,186, filed Feb. 5, 2019, the contents of which are incorporated herein by reference in their entireties.

BACKGROUND

[0002] Battery packs may be used with different types of equipment, including outdoor power equipment, vehicles, aerial man lifts, floor care devices, golf carts, lift trucks and other industrial vehicles, floor care devices, recreational utility vehicles, industrial utility vehicles, lawn and garden equipment, and energy storage or battery backup systems. Outdoor power equipment includes lawn mowers, riding tractors, snow throwers, pressure washers, portable generators, tillers, log splitters, zero-tum radius mowers, walk-behind mowers, riding mowers, and turf equipment such as spreaders, sprayers, seeders, rakes, and blowers. Outdoor power equipment may, for example, use one or more electric motors to drive an implement, such as a rotary blade of a lawn mower, a pump of a pressure washer, the auger of a snow thrower, the alternator of a generator, and/or a drivetrain of the outdoor power equipment. Vehicles include cars, trucks, automobiles, motorcycles, scooters, boats, all-terrain vehicles (ATVs), personal water craft, snowmobiles, utility vehicles (UTVs), and the like.

SUMMARY

[0003] The present disclosure relates generally to battery packs that can be used to provide electrical power to vehicles and other equipment. More specifically, the present disclosure relates to the design and manufacture of cell module assemblies for use in battery packs.

[0004] In one embodiment, a cell module assembly is provided. The cell module assembly includes a top frame, a bottom frame spaced apart from the top frame, multiple lithium-ion battery cells, a top collector plate, a bottom collector plate, and curable adhesive. The top frame has protrusions extending away from the top frame to define first multiple pockets. The bottom frame also has protrusions extending away from the bottom frame toward the top frame to define second multiple pockets. The second multiple pockets includes pockets axially aligned with the first multiple pockets. The multiple lithium-ion battery cells are each adhesively coupled to the bottom frame and the top frame. The multiple lithium-ion battery cells extend between the bottom frame and top frame. The multiple lithium-ion battery cells are each received within a pocket in the first multiple pockets and a pocket in the second multiple pockets. The multiple lithium-ion battery cells are connected in parallel. The top collector plate is electrically connected to the multiple lithium-ion battery cells and is adhesively coupled to the top frame. The top collector plate defines first multiple apertures above the first multiple pockets. The bottom collector plate is electrically

connected to the multiple lithium-ion battery cells and is adhesively coupled to the bottom frame. The bottom collector plate defines second multiple apertures below the second multiple pockets. The curable adhesive is received within each window in the first multiple pockets. The curable adhesive contacts the top frame and each of the multiple lithium-ion battery cells in at least two separate locations to adhesively couple each lithium-ion battery cell to the top frame.

[0005] In another embodiment, a cell module assembly includes a top frame, a bottom frame, multiple lithium-ion battery cells, a top collector plate, a bottom collector plate, and a compression limiter. The top frame defines a first multiple pockets and includes a first collar formed on an outer perimeter of the top frame. The bottom frame is spaced apart from the top frame and defines a second multiple pockets axially aligned with the first multiple pockets. The bottom frame includes a second collar formed on an outer perimeter of the bottom frame and axially aligned with the first collar. Each of the multiple lithium-ion battery cells are coupled to and extend between the bottom frame and the top frame. Each of the multiple lithium-ion battery cells are received within a pocket in the first multiple pockets and a pocket in the second multiple pockets. The top collector plate is electrically connected to the multiple lithium-ion battery cells and is coupled to the top frame. The bottom collector plate is electrically connected to the multiple lithium-ion battery cells and is coupled to the bottom frame. The compression limiter is received within and extends between the first collar and the second collar.

[0006] In another embodiment, the cell module assembly includes a first frame, a second frame, multiple lithium-ion battery cells, a first collector plate, and a second collector plate. The first frame defines a first multiple pockets. The first frame has an outer perimeter including mating tabs extending outward from the outer perimeter and mating notches extending inward from the outer perimeter. The second frame is spaced apart from the first frame and defines a second multiple pockets axially aligned with the first multiple pockets. Each of the multiple lithium-ion battery cells are coupled to and extend between the second frame and the first frame. Each of the multiple lithium-ion battery cells are received within a pocket in the first multiple pockets and a pocket in the second multiple pockets. The first collector plate is electrically connected to the multiple lithium-ion battery cells and is coupled to the first frame. The second collector plate is electrically connected to the multiple lithium-ion battery cells and is coupled to the second frame.

[0007] In some embodiments, the cell module assembly includes a battery monitoring system including a sensor for monitoring lithium-ion battery use and a controller for determining lithium-ion battery useful life. In some embodiments, the cell module assembly omits fasteners.

[0008] The cell module assemblies can include mating features that allow several cell module assemblies to be coupled together to form a battery pack. For example, two or more cell module assemblies are electrically connected together and installed into a vehicle or other equipment. Cell module assemblies can be connected in series or in parallel, and can be stacked vertically or horizontally relative to another cell module assembly to provide a desired amount of power to a vehicle or piece of equipment.

[0009] In another embodiment, a method of assembling a cell module assembly is provided. The method includes positioning a lithium-ion battery cell within a first pocket formed in a top frame and within a second pocket formed in a bottom frame opposite the top frame. The method includes coupling a top collector plate to the top frame above the lithium-ion battery cell and coupling a bottom collector plate to the bottom frame below the lithium-ion battery cell. Adhesive is then applied to the bottom collector plate and into a plurality of passages formed in the bottom collector plate. The passages formed in the bottom collector plate allow adhesive to pass beyond the bottom collector plate, onto the bottom frame, and into the second pocket through at least two windows offset by at least 90 degrees. The adhesive then contacts the lithium-ion battery cell in at least two separate directions. The adhesive is then cured. Next, adhesive is applied to the top collector plate and into a plurality of passages formed in the top collector plate. The passages formed in the top collector plate allow adhesive to pass beyond the top collector plate, onto the top frame, and into

the first pocket through at least two windows angularly offset by at least 90 degrees. The adhesive then contacts the lithium-ion battery cell in at least two separate directions. Next, the adhesive is cured.

[0010] In another embodiment, a cell module assembly includes a first frame having a first plurality of pockets, a second frame spaced apart from the first frame and having a second plurality of pockets, a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame by a first curable adhesive, and a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame by a second curable adhesive. Each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets.

[0011] In another embodiment, a cell module assembly includes a first frame defining a first plurality of pockets and a second frame spaced apart from the first frame and defining a second plurality of pockets. The first frame includes a first collar extending outwardly from an outer perimeter of the first frame. The second frame includes a second collar extending outwardly from an outer perimeter of the second frame. The first collar being axially aligned with the second collar. The cell module assembly further includes a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame, a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame, and a compression rod received within and extending between the first collar and the second collar. Each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets.

[0012] In another embodiment, a cell module assembly includes a first frame defining a first plurality of pockets and a second frame spaced apart from the first frame and defining a second plurality of pockets. The first frame includes an outer perimeter having one or more mating tabs extending outwardly from the outer perimeter and one or more mating notches extending inwardly into the outer perimeter. The cell module assembly further includes a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame, and a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame. Each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets.

[0013] Alternative exemplary embodiments relate to other features and combinations of features as may be generally recited in the claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1 is a perspective view of a cell module assembly according to embodiments of the disclosure.

[0015] FIG. 2A is a top perspective view of a bottom frame of the cell module assembly of FIG. 1.

[0016] FIG. 2B is a bottom perspective view of the bottom frame of FIG. 2A.

[0017] FIG. 2C is a detailed view of pockets and a collar formed in the bottom frame of FIG. 2A.

[0018] FIG. 2D is a top view of the bottom frame of FIG. 2A.

[0019] FIG. 2E is a front view of the bottom frame of FIG. 2A.

[0020] FIG. 2F is a bottom view of the bottom frame of FIG. 2A.

[0021] FIG. 3A is a top perspective view of a top frame of the cell module assembly of FIG. 1.

[0022] FIG. 3B is a detailed view of locating and mounting features present in the top frame of FIG. 3A.

[0023] FIG. 3C is a bottom perspective view of the top frame of FIG. 3A.

[0024] FIG. 3D is a top view of the top frame of FIG. 3A.

[0025] FIG. 3E is a front view of the top frame of FIG. 3A.

[0026] FIG. 3F is a bottom view of the top frame of FIG. 3A.

[0027] FIG. 4A is a top perspective view of a bottom collector plate of the cell module assembly of FIG. 1.

[0028] FIG. 4B is a bottom view of the bottom collector plate of FIG. 4A.

[0029] FIG. 4C is a top, front perspective view of the bottom collector plate of FIG. 4A.

[0030] FIG. 5A is a top perspective view of a top collector plate of the cell module assembly of FIG. 1.

[0031] FIG. 5B is a bottom perspective view of the top collector plate of FIG. 5A.

[0032] FIG. 5C is a front view of the top collector plate of FIG. 5A.

[0033] FIG. 6 is a top perspective view of an array of lithium-ion battery cells of the cell module assembly of FIG. 1.

[0034] FIG. 7A is a top view of the cell module assembly of FIG. 1.

[0035] FIG. 7B is a bottom view of the cell module assembly of FIG. 1.

[0036] FIG. 7C is a front view of the cell module assembly of FIG. 1.

[0037] FIG. 7D is a detailed top perspective view of the cell module assembly of FIG. 1, showing interactions between the top frame of FIG. 3A and the top collector plate of FIG. 5A.

[0038] FIG. 7E is a cross-sectional view of the cell module assembly of FIG. 1, taken along line 7E-7E in FIG. 7A.

[0039] FIG. 7F is a cross-sectional view of the cell module assembly of FIG. 1, taken along line 7F-7F in FIG. 7A.

[0040] FIG. 7G is a cross-sectional view of the cell module assembly of FIG. 1, taken along line 7G-7G in FIG. 7A.

[0041] FIG. 7H is a detail view of the cross-sectional view of FIG. 7F.

[0042] FIG. 7I is a perspective view of a cross-section of the cell module assembly of FIG. 1, taken along lines 7I-7I in FIG. 7A.

[0043] FIG. 8 is a perspective view of a compression limiter of the cell module assembly of FIG. 1.

[0044] FIG. 9 is a top view of multiple cell module assemblies as depicted in FIG. 1, detailing where mating features formed on each cell module assembly can be coupled together to form a battery pack.

[0045] FIG. 10 is a process diagram depicting a method of assembling a cell module assembly, such as the cell module assembly of FIG. 1.

[0046] FIG. 11 is a perspective view of a cell module assembly according to other embodiments of the disclosure.

DETAILED DESCRIPTION

[0047] Before turning to the figures, which illustrate certain exemplary embodiments in detail, it should be understood that the present disclosure is not limited to the details or methodology set forth in the description or illustrated in the figures. It should also be understood that the terminology used herein is for the purpose of description only and should not be regarded as limiting.

[0048] Referring to FIG. 1, a cell module assembly (“CMA”) **100** is illustrated according to an exemplary embodiment of the disclosure. The CMA **100** includes multiple battery cells **102**, which can together output power to operate a vehicle or other equipment. In some embodiments, the battery cells **102** are lithium-ion battery cells. The battery cells **102** can be lithium-ion battery cells rated at 3.6 volts and 3 amp-hours, for example. As illustrated, the CMA **100** includes thirty-two

battery cells **102** arranged in four rows of eight cells each. The battery cells **102** are electrically connected to one another using conducting wires **107** having terminals **103**, **105**, **109** coupled (e.g., wire bonded) to each battery cell **102** and a common conductor (e.g., a top collector plate **400** or bottom collector plate **300**). The CMA **100** can be identified with an individual identifier (e.g., serial number, bar code, etc.) for use by the CMA manufacturer to track, categorize, evaluate, or record information or data about an individual CMA.

[0049] The battery cells **102** are supported by a top frame **104** and a bottom frame **106**. The top frame **104** and the bottom frame **106** can each be continuous components formed of insulating polymeric materials. As shown in FIGS. 2A-2F, the bottom frame **106** includes a generally rectangular base **108** including a series of cylindrical protrusions **110** extending upwardly away from the base **108**. The cylindrical protrusions **110** define a series of pockets **112** that can each receive a battery cell **102**, for example. Each pocket **112** can include a generally circular base **114** circumscribed by the cylindrical protrusion **110** associated with the pocket **112**. In some embodiments, a terminal hole **116** is formed through the base **114**. The terminal hole **116** can be approximately centered within the base **114** to allow a terminal (e.g., terminal **103**, **105**, shown in FIG. 6) of a battery cell **102** to extend through the bottom frame **106**. Alternatively, the terminal **103**, **105** may be entirely contained within the pocket **112**, and the terminal hole **116** allows access to the terminal **103**, **105**, as shown in FIG. 7E. Access to the terminal **103**, **105** or the battery cell **102**, generally, can be helpful in assembly and/or maintenance processes where wire bonds between the terminals **103**, **105** and battery cells **102** are being created or repaired. In some examples, the base **114** includes a sunken section **118** surrounding a portion of the terminal hole **116**. The sunken section **118** can extend around more than half of the terminal hole **116**, for example. Windows **120** can be formed in the base **114** and/or the cylindrical protrusions **110** to define adhesive flow paths through the bottom frame **106** onto the battery cells **102** positioned within the pockets **112**, as explained in additional detail below.

[0050] Collars **122**, **124** can be positioned about the outer perimeter of the generally rectangular base **108**. In some examples, the collars **122**, **124** are positioned on opposite sides of the bottom frame **106**. The collars **122**, **124** can each have a cylindrical inner wall **126**, **128** extending from a first axial end surface **130**, **132** of the collars **122**, **124** to a second axial end surface **134**, **136** of the collars **122**, **124**. The cylindrical inner walls **126**, **128** each define a bore **138**, **140**. In some embodiments, the first axial end surface **130**, **132** extends approximately parallel to an uppermost surface **142** of the bottom frame **106**. The uppermost surface **142** can correspond with an uppermost surface of each cylindrical protrusion **110**, for example. In some embodiments, the first axial end surfaces **130**, **132** and the uppermost surface **142** of the bottom frame **106** form a continuous planar surface.

[0051] A spacer **144** can extend outward from one side of the bottom frame **106**. In some embodiments, the spacer **144** extends away from an outermost set of pockets **112** to form a platform **146** having a generally planar bottom surface **148**. Ribs **150** can extend from the cylindrical protrusions **110** outward to an outer platform surface **152** to provide additional support to the platform **146**, or to provide a flange for mounting or support purposes.

[0052] The bottom surface **154** of the bottom frame **106** can include a series of locating features **156**, **158** that protrude away from the bottom surface **154**. In some embodiments, the locating features **156**, **158** are grouped in pairs of two distinct and spaced apart walls surrounding each terminal hole **116** in the bottom frame **106**. The locating features **156**, **158** can have an arcuate shape defined by an identical radius, and can be positioned concentric with the terminal hole **116**. The locating features **156**, **158** can be used to help locate a bottom collector plate (**300**, shown in FIG. 4A-4C) and shield terminal connections between terminals of the battery cells **102** and the bottom collector plate **300**, as explained below. In some embodiments, the locating features **156**, **158** can be arranged in groups of two, and a groove **157** formed into the bottom surface **154** can extend between each pair of locating features **156**, **158**.

[0053] The bottom surface **154** includes recesses formed into the bottom frame **106** to define adhesive flow paths. The recesses can direct adhesive around battery cells **102** during the CMA assembly process (e.g., the CMA assembly process **500**), which can help create a robust coupling between battery cells **102** and the bottom frame **106**. For example, mounting holes **160** can be formed through the bottom frame **106**. In some embodiments, the mounting holes **160** are aligned to straddle two adjacent pockets. The mounting holes **160** can define the windows **120** formed in the cylindrical protrusions **110** and/or bases **114** discussed above. The outermost pockets **112** formed in the bottom frame **106** can be surrounded by additional recesses, including channels **162** and trenches **164**. The channels **162** can extend between multiple pockets **112**, and can extend to windows **120** formed in two different cylindrical protrusions **110** or bases **114**. The trenches **164** can be positioned near the outermost pockets **112** in the pocket array. Each of the recesses can be oriented to direct adhesive radially inward into each pocket **112**, in a direction generally normal to the cylindrical protrusions **110**.

[0054] One or more supports **166** can extend away from the bottom surface **154** of the bottom frame **106**. The supports **166** can be spaced about the bottom frame **106** and positioned to more evenly distribute loading experienced by the bottom frame **106** (e.g., from battery cell weight **102**, additional CMA's, etc.) throughout the component. In some examples, the supports extend away from the bottom surface **154** of the bottom frame **106** to a support surface **168** extending approximately planar with the second axial end surfaces **134**, **136** of the collars **122**, **124**. The supports **166** can include one or more legs **170** to provide balance.

[0055] The bottom frame **106** can include a combination of mating tabs **172** and mating notches **174** positioned about the outer perimeter of the base **108**. In some examples, mating tabs **172** are formed on a first side **176** of the base **108** and extend outwardly away from the base **108**, while mating notches **174** are formed into a second side **178** of the base **108** opposite the first side **176** and extend into the outer perimeter of the base **108**. The mating tabs **172** and mating notches **174** can have a complimentary geometry (e.g., the mating tabs **172** can be received within the mating notches **174** to form a coupling). Each of the mating tabs **172** may taper outwardly as the tab **172** extends away from the base **108**. Similarly, each of the mating notches **174** may taper outwardly as the mating notch **174** extends into the base **108**. The third side **180** and the fourth side **182** can each include a mating tab **172** and a mating notch **174**. In some embodiments, a mating tab **172** extends outwardly away from each of the collars **122**, **124**. Optionally, flanges **184** including slots **186** can extend away from the third and fourth sides **180**, **182**, collectively.

[0056] The top frame **104** of the CMA **100**, as shown in FIGS. 3A-3F, can include many of the same features present in the bottom frame **106** that were previously discussed above. Because the top frame **104** can even be a substantial mirror image of the bottom frame **106** in some embodiments, components present in the top frame **104** having common names in both the bottom frame **106** and the top frame **104** should be considered to have the same or substantially similar geometries, orientations, structures, or relationships to other components as described above with reference to the bottom frame **106**, unless specified otherwise. For brevity, some of the description of like components having like names present in both the bottom frame **106** and the top frame **104** has been omitted, but should be considered to be incorporated herein by reference in its entirety.

[0057] As shown in FIGS. 3A-3F, the top frame **104** also includes a generally rectangular base **208**. A series of cylindrical protrusions **210** extend upwardly away from the base **208** to define another series of pockets **212** that can each receive a battery cell **102**. Each pocket **212** can include a generally circular base **214** circumscribed by the cylindrical protrusion **210** associated with the pocket **212**. A terminal hole **216** can be formed through the base **214**. Windows **220** can be formed in the base **214** and/or the cylindrical protrusions **210** to define adhesive flow paths through the top frame **104** onto the battery cells **102** positioned within the pockets **212**, as explained in additional detail below.

[0058] Collars **222**, **224** can be positioned about the outer perimeter of the generally rectangular

base **208**. The collars **222, 224** can be positioned on opposite sides of the top frame **104**, and can be axially aligned with the collars **122, 124** formed on the bottom frame **106**. The collars **222, 224** can each have a cylindrical inner wall **226, 228** extending from a first axial end surface **230, 232** of the collars **222, 224** to a second axial end surface **234, 236** of the collars **222, 224**. The cylindrical inner walls **226, 228** each define a bore **238, 240**. In some embodiments, the first axial end surface **230, 232** of each collar **222, 224** extends approximately parallel to a lowermost surface **242** of the top frame **206**. The lowermost surface **242** can correspond with a lowermost surface of each cylindrical protrusion **210**, for example. The first axial end surfaces **230, 232** and the lowermost surface of the top frame **104** can form a continuous planar surface.

[0059] A spacer **244** can extend outward from one side of the top frame **104**. Like the spacer **144**, the spacer **244** extends away from an outermost set of pockets **212** to form a platform **246** having a generally planar top surface **248**. Ribs **250** can extend from the cylindrical protrusions **210** outward to an outer platform surface **252** to provide additional support to the platform **246**, or to provide a flange for mounting or support purposes. The platform **246** can also include through holes **251** that can receive inserts **253** (shown in FIG. 7A). The inserts **253** can be threaded, metallic components (e.g., fasteners or threaded bushings) that can be used to mount the CMA **100** within a vehicle or piece of equipment. Alternatively, the inserts **253** can receive additional conductors, which are placed in electrical communication with one or more of the battery cells **102** through the top collector plate **400**, as explained below. The additional conductors coupled to the inserts **253** can extend to other CMAs **100** (e.g., to form a battery pack) or to systems on a vehicle or equipment to deliver power from the battery cells **102**, for example.

[0060] A top surface **254** of the top frame **104** can include a series of locating features **256, 258** that protrude away from the top surface **254**. In some embodiments, the locating features **256, 258** are grouped in pairs of two distinct and spaced apart walls surrounding each terminal hole **216** in the bottom frame **106**. The locating features **256, 258** can each have an arcuate shape defined by an identical radius, and can be positioned concentric with the terminal hole **216**. The locating features **256, 258** can be used to help locate a top collector plate (**400**, shown in FIG. 5A-5C) and shield terminal connections between terminals of the battery cells **102** and the top collector plate **400**, as explained below. In some embodiments, the locating features **256, 258** can be arranged in groups of two, and a groove **257** formed into the top surface **254** can extend between each pair of locating features **256, 258**.

[0061] The top surface **254** includes recesses formed into the top frame **104** to define adhesive flow paths. The recesses can direct adhesive around battery cells **102** during the CMA assembly process (e.g., the CMA assembly process **500**), which can help create a robust coupling between battery cells **102** and the top frame **104**. For example, mounting holes **260** can be formed through the top frame **104**. The mounting holes **260** can also be aligned to straddle two adjacent pockets **212**. The mounting holes **260** can define the windows **220** formed in the cylindrical protrusions **210** and/or bases **214** discussed above. The outermost pockets **212** formed in the top frame **104** can be surrounded by additional recesses, including channels **262** and trenches **264**.

[0062] One or more supports **266** can extend away from the top surface **254** of the top frame **104**. The supports **266** can be spaced about the top frame **104** and positioned to more evenly distribute loading experienced by the top frame **104** (e.g., from additional CMA's, etc.) throughout the component. In some examples, the supports **266** extend away from the top surface **254** of the top frame **104** to a support surface **268** extending approximately planar with the second axial end surfaces **234, 236** of the collars **222, 224**. The supports **266** can have one or more distinct shapes.

[0063] The top frame **104** can also include mating tabs **272** and mating notches **274** positioned about the outer perimeter of the base **208**. In some examples, mating tabs **272** are formed on a first side **276** of the base **208** and extend outwardly away from the base **208**, while mating notches **274** are formed into a second side **278** of the base **208** opposite the first side **276** and extend into the outer perimeter of the base **208**. The mating tabs **272** and mating notches **274** can have a

complimentary geometry. A third side **280** and a fourth side **282** of the top frame **104** can each include a mating tab **272** and a mating notch **274**. In some embodiments, a mating tab **272** extends outwardly away from each of the collars **222**, **224**. In some embodiments, the mating tabs **172** and mating tabs **272** are vertically aligned. Similarly, the mating notches **174**, **274** can be vertically aligned.

[0064] The battery cells **102** in the CMA **100** can be placed in electrical communication with one another using a bottom collector plate **300** and a top collector plate **400**, as shown in FIGS. **4A-4C** and **5A-5C** respectively. The collector plates **300**, **400** can be formed of an electrically conducting metallic material (e.g., copper, aluminum) that can receive and conduct current through terminals **103**, **105** extending away from each battery cell **102**. In some embodiments, each of the battery cells **102** includes a positive terminal **103** connected to the top collector plate **400** and a negative terminal **105** connected to the bottom collector plate **300**. Conversely, each of the positive terminals **103** could be connected to the bottom collector plate **300** while each of the negative terminals **105** could be connected to the top collector plate **400**.

[0065] Each of the collector plates **300**, **400** include a series of apertures **302**, **402** formed through a generally rectangular base **304**, **404**. The number of apertures **302**, **402** formed through each collector plate **300**, **400** can correspond to the number of battery cells **102** that are present in or that could be present in the CMA **100**. The bottom collector plate **300** can be coupled to the bottom frame **106** so that each aperture is positioned below a pocket **112** of the bottom frame **106**. Each aperture **302** can be aligned with (i.e., overlapping to some extent) a terminal hole **116** in the bottom frame **106**. The overlapping orientation can allow a terminal **103**, **105** of a battery cell **102** received within the pocket **112** to extend downward through the bottom frame **106** and the bottom collector plate **300** to make an electrical connection with a bottom surface **306** of the bottom collector plate **300**. Similarly, the top collector plate **400** can be coupled to the top frame **104** so that each aperture **402** is positioned above a pocket **212** of the top frame **104**. Each aperture **402** can also be aligned with a terminal hole **216** in the top frame **104** so that a terminal **103**, **105** of a battery cell **102** received within a pocket **212** can extend through the top frame **104** and the base **404**. The terminal **103**, **105** can be bent back toward the base **104**, where it can be coupled (e.g., fused) to an upper surface **406** of the top collector plate **400**.

[0066] The collector plates **300**, **400** each have generally complimentary geometry to seat upon the bottom frame **106** and top frame **104**. For example, the apertures **302**, **402** can be defined by a generally elongate oval shape that can be received around the locating features **156**, **158**, **256**, **258**. The shape of the apertures **302**, **402** can form a clearance fit around the locating features **156**, **158**, **256**, **258** to help position the collector plates **300**, **400** during assembly of the CMA **100**. The size and orientation of the locating features **156**, **158**, **256**, **258** relative to the size of the apertures **302**, **402** restricts movement of the collector plates **300**, **400** once the collector plates **300**, **400** are properly seated upon their respective frame **104**, **106**. Generally rectangular ridges **308**, **408** formed between apertures **302**, **402** can extend away from the base **304**, **404** to sit upon and engage the grooves **157**, **257** extending between locating features **156**, **158**, **256**, **258**. A mounting tab **310**, **410** including mounting holes **312**, **412** can extend outward from the base **304**, **404**. The mounting tab **310**, **410** can extend above and sit flatly upon the platforms **146**, **246**, for example. In some embodiments, the mounting holes **312**, **412** are used to create electrical connections with inserts **253**, additional CMAs **100**, equipment to be powered, negative buses, and the like. Optionally, the mounting holes **312**, **412** can receive fasteners, although some embodiments of the CMA **100** omit fasteners entirely. Arms **314** can extend away from the base **304** of the bottom collector plate **300** in a direction generally perpendicular to the base **304**. The arms **314** can be received within and engaged by the slots **186**, for example, when the bottom collector plate **300** is properly positioned relative to the bottom frame **106**. Holes **316**, **416** sized to surround the supports **166**, **266** extending away from each frame **104**, **106** can be formed through the base **304**, **404** as well.

[0067] The collector plates **300**, **400** can also include a plurality of fingers **320**, **420** extending

away from the base **304**, **404** to define adhesive passages. The fingers **320**, **420** can extend from each base **304**, **404** toward each respective frame **104**, **106**. For example, the fingers **320** can extend upwardly from the base **304** of the bottom collector plate **300** and the fingers **420** can extend downwardly away from the base **404** of the top collector plate **400**.

[0068] The shape and positioning of the fingers **320**, **420** relative to the bottom frame **106** and top frame **104** helps the CMA assembly process in several ways. First, the fingers **320**, **420** can help secure the collector plates **300**, **400** to the frames **104**, **106**. In some embodiments, each finger **320**, **420** is positioned about the collector plate **300**, **400** to engage a recess formed in the bottom frame **106** or top frame **104**. The fingers **320**, **420** can be arranged to extend into and engage one or more walls associated with the mounting holes **160**, **260**, channels **162**, **262**, or trenches **164**, **264** to define adhesive passages extending through the top collector plate **300**, **400** and into the frames **104**, **106**. The fingers **420** can extend downwardly and obliquely away from the top collector plate **400**, which can help secure the top collector plate **400** onto the top frame **104**. Similarly, the fingers **320** can extend upwardly and obliquely away from the bottom collector plate **300** to engage walls of the recesses and resist forces pulling the bottom collector plate **300** outward from the bottom frame **106**. The fingers **320**, **420** can include pairs of fingers **320A**, **320B**, **420A**, **420B** extending toward one another, individual fingers **320C**, **420C** extending outwardly from the bases **304**, **404**, or a combination of each, for example.

[0069] The fingers **320**, **420** can also help guide adhesive into and around the pockets **112**, **212** of the frames **104**, **106**, which can help secure battery cells **102** within the CMA **100**. In some embodiments, fingers **320**, **420** extend away from the bases **304**, **404** and can help guide or separate adhesive flow to create multiple distinct flow paths of adhesive around and into the pockets **112**, **212** when the CMA is assembled. For example, the fingers **320**, **420** can extend away from the bases **304**, **404** to form angles α of between about 5 degrees and about 90 degrees with the bases **304**, **404**. In some embodiments, the angles between the fingers **320**, **420** and the bases **304**, **404** are between about 20 degrees and about 80 degrees, and could be between about 50 degrees and 70 degrees. The angle of the fingers **320**, **420** can be chosen based upon a viscosity of the adhesive intended to secure the collector plates **300**, **400** to the bottom frame **106** and top frame **104** respectively. For example, larger angles (e.g., angles closer to 90 degrees) can be used for lower viscosity adhesives, while smaller angles (e.g., angles closer to 5 degrees) can be chosen when working with higher viscosity adhesives.

[0070] Referring now to FIG. **6**, the battery cells **102** of the CMA **100** are depicted. In some embodiments, all thirty-two battery cells **102** are connected in parallel in a 1S32P (one series, thirty-two parallel) arrangement by a single top collector plate **400** and a single bottom collector plate **300**. In other embodiments, two groups of sixteen battery cells **102** are connected in parallel with the two groups connected in series in a 2S16P (two series, sixteen parallel) arrangement, as shown in FIG. **11**. Two top collector plates **400a**, **400b** and two bottom collector plates **300A**, **300B** can be used to connect the thirty-two battery cells **102**. Each top collector plate **400A**, **400A** and each bottom collector plate **300A**, **300B** can support and connect sixteen battery cells **102** in parallel. The two sets of sixteen battery cells **102** can then be electrically coupled together (e.g., by electrically connecting the top collector plate **400A** to the top collector plate **400B** and electrically connecting the bottom collector plate **300A** to the bottom collector plate **300B**) to place the sets of sixteen battery cells **102** in series with one another. Arranging a relatively large number of battery cells **102** in parallel in this manner helps to slow the degradation of the charge capacity of the CMA **100**. In other embodiments, the number of battery cells **102** in the CMA **100** may be greater or fewer and the connection arrangements between the battery cells **102** may vary depending on the ratings needed from a particular CMA (e.g., voltage, capacity, power, etc.). Each battery cell **102** can have a positive terminal **103** and a negative terminal **105**, depicted in FIG. **7B**.

[0071] In some embodiments, the CMA **100** also includes an electronic controller **440**, as shown in FIG. **6**. The electronic controller **440** can include a processor and a memory device. The processor

can be implemented as a general purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable electronic processing components. The memory device (e.g., memory, memory unit, storage device, etc.) is one or more devices (e.g., RAM, ROM, Flash memory, hard disk storage, etc.) for storing data and/or computer code for completing or facilitating the various processes, layers and modules described in the present application. The memory device may be or include volatile memory or non-volatile memory. The memory device may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present application. According to an exemplary embodiment, the memory device is communicably connected to processor via processing circuit and includes computer code for executing (e.g., by processing circuit and/or processor) one or more processes described herein.

[0072] The controller **440** also implements a battery management system (BMS) for regulating the currents and/or voltages involved in the charging and discharging processes in order to ensure that the battery cells **102** are not damaged or otherwise brought to problematic charge states. For example, the BMS may block an electrical current from being delivered to the cells **102**, or may block a current being drawn from the cells **102** based the current and voltage properties of the signal and/or of the CMA **100**. The BMS may also implement controls based a temperature as detected by a temperature sensor and regulate operation of the CMA **100** based on over temperature or under temperature conditions determined by the detected temperature.

[0073] The maximum charge capacity of the cells **102** of the CMAs **100** of a battery pack decay of over the life of the battery pack as the battery pack ages. This decay is caused by the battery pack being cycled by discharging and then recharging the battery pack, changes in temperature (e.g., high temperatures), and degradation of the chemistry of the battery cells. A cycle is the transition from the battery pack's fully charged state (as allowed by the BMS) to its fully discharged state (as allowed by the BMS). As the number of cycles increases over the life of the battery pack, the battery pack's maximum charge capacity declines.

[0074] The electronic controller **440** of each CMA **100**, if present, can be programmed to store data related to the operation of that CMA **100** and to use that data to determine a useful life measurement for that CMA **100**. The useful life measurement may be expressed in terms of a percentage of life (e.g., the CMA is at 100% life when brand new). The useful life measurement may be used to set multiple end of life thresholds tied to certain applications for the CMA. For example, a CMA **100**'s first life could extend between 100% and 70% charge capacity where the CMA **100** would be suitable for use powering a commercial lawn mower. After the end of the first life (e.g., a useful life measurement below 70%), a CMA **100** could be reconditioned and put to use in its second life (e.g., between 70% and 50%) in which the CMA **100** is suitable for use in a battery pack for equipment having lower energy requirements than the equipment powered by the CMA **100** during its first life.

[0075] The useful life measurement can be determined by a number of data points indicative of useful life that can be monitored and saved by the electronic controller **440**. These useful life indicators include charge capacity, days or other time elapsed since a commissioning date when the CMA **100** is first put into service, number of cycles since the commissioning date, depth of cycle for individual cycles or groups of cycles, an electrical charge tracker that counts the number of coulombs supplied by the CMA **100** since the commission date, an event counter of operation of the CMA **100** in extreme temperature conditions (e.g., above 140 degrees Fahrenheit) for individual events or groups of events, the current supplied by the CMA **100**, the current received by the CMA **100** for charging, the voltage supplied by the CMA **100**, and/or the voltage applied to the CMA **100** during charging. In different embodiments, different combinations of useful life indicators are monitored and saved by the electronic controller **440**. The useful life indicators identified above may be monitored individually in some embodiments or monitored in any combination in other

embodiments. In other embodiments, useful life indicators are tracked and stored for each individual battery cell **102** of the CMA **100**.

[0076] Gathering and tracking useful life indicators across the life of the CMA rather than a single instantaneous reading indicative of the end of life (e.g., 70% charging capacity) provides additional information to classify a CMA **100** for reconditioning to an appropriate use. In some embodiments, not every data point associated with a useful life indicator is stored, for example temperature may be sampled and stored on a weekly basis rather than daily basis. CMAs **100** may be classified where different classifications are suitable for use in different second lives or based on different expected future performance in the second life as determined by the evaluation of the useful life indicators from the first life. Tracking useful life indicators also provides the CMA manufacturer with data that can be used for diagnostics to determine why a particular CMA performs better or worse than a similar CMA and then use that diagnostic information to improve manufacturing or other processes for new CMAs.

[0077] For example, a CMA **100** with 70% charging capacity, but a relatively high number of days operated in extreme temperature conditions may have its charging capacity degrade at a faster rate than a CMA **100** with a 70% charging capacity and no days operated in extreme temperature conditions. Both CMAs **100** may be suitable for reconditioning and use in their second lives, but the appropriate uses for the two CMAs in their second lives may be different based on their classification resulting from evaluation of their respective useful indicators. Tracking and storage of useful life indicators can also be used to evaluate returned or warranted battery packs, fix or refurbish battery packs returned within their first life, and improve manufacturing processes by comparing various CMAs to one another.

[0078] The useful life indicators are used to identify when a CMA **100** has reached an end of life threshold. The CMA **100** may have multiple end of life thresholds. For example, the CMA **100** may be suitable for use in a first application during the span of its first life (e.g., a commercial lawn mower). When the CMA **100** reaches its first end of life threshold (e.g., 80%, 75%, 70%, etc. of its useful life), the CMA **100** is taken out of service for the first application and returned to the CMA manufacturer. The CMA manufacturer then categorizes or classifies the CMA **100** based on its useful life data to identify a suitable second life application for that particular CMA **100**. If necessary, that CMA **100** is reconditioned or refurbished and then combined with other similarly classified CMAs to form a battery pack for use in a second life application. This new battery pack can be used in the second life application until the CMA reaches a second end of life threshold (e.g., 50%, 45%, 40%, etc. of its useful life). This method of using the same CMA for different applications based on the CMA's life cycle allows the CMA manufacturer to make more complete use of the CMA's available capacity by using the CMA in multiple applications rather than having a CMA at the end of its first life discarded and not make use of the remaining battery capacity.

[0079] The CMA manufacturer may lease battery packs consisting of multiple CMAs to the user of the equipment powered by the battery pack. This approach would enable the user of the CMA during its first life to return the battery pack at the end of its first life to the CMA manufacturer, allowing the CMA manufacturer to classify the CMAs and reuse them for second life applications, where the resulting battery packs could again be leased or sold to the user of the equipment powered by the battery pack consisting of CMAs in their second life. Alternatively, the CMA manufacturer can sell the battery packs consisting of CMAs and buy back the battery packs at the end of the first life of the CMAs for classification and reuse in a second life application.

[0080] The CMA **100** can be assembled using a process **500** illustrated in FIG. **10**, with reference to each of FIGS. **1-9** and **11**. Initially, the top frame **104** and bottom frame **106** are provided. As indicated above, the top frame **104** and the bottom frame **106** can each be injection molded polymeric components. In some embodiments, the top frame **104** and bottom frame **106** are each formed of electrically insulating materials.

[0081] At step **502**, battery cells **102** are positioned in each pocket **112**, **212** formed in the top and

bottom frames **104**, **106**. The pockets **212** in the top frame **104** can be axially aligned with the pockets **112** in the bottom frame **106**, so that each cylindrical battery cell **102** can be simultaneously received within both pockets **112**, **212**. The battery cells **102** can abut the bases **114**, **214** of each pocket, and can include terminals **103**, **105** extending through each of the terminal holes **116**, **216** formed through the bottom frame **106** and top frame **104** respectively.

[0082] During step **502**, one or more compression limiters **460**, shown in FIG. **8**, can be placed within the collars **122**, **124**, **222**, **224** formed in the bottom frame **106** and top frame **104**. The compression limiters **460** can have a generally tubular shape defined by a cylindrical outer surface **466** having widened sections **462**, **464** formed at each axial end of the compression limiter **460**. The collars **122**, **124** on the bottom frame **106** can be axially aligned with the collars **222**, **224** on the top frame **104**, so that each compression limiter **460** extends between two collars.

[0083] The compression limiters **460** can be defined by a height (i.e., a longitudinal length) that is larger than a height of each battery cell **102**. By being taller than the battery cells **102**, compressive loading experienced by either of the frames **104**, **106** is initially diverted to the compression limiters **460**, which engage the collars **122**, **124**, **222**, **224**. The compression limiters **460** keep the bottom frame **106** and the top frame **104** at a fixed distance apart from one another, which prevents the frames **104**, **106** from applying extreme or otherwise unwanted compressive stress to each battery cell **102** that could be caused by loading from another CMA positioned above the CMA **100**, for example.

[0084] At step **504**, the top collector plate **400** is coupled to the top frame **104**. The top collector plate **400** can be positioned above the top frame **104**, then urged downward until the base **404** of the top collector plate **400** engages the top surface **254** of the top frame **104**. Once properly seated upon the top frame **104**, locating features **256**, **258** extend through each aperture **402**, ridges **408** extend into each groove **257** in the top frame **104**, and supports **266** extend through each hole **416**. Fingers **420** of the top collector plate **400** extend downwardly into recesses in the top frame **104**, including the mounting holes **260**, the channels **262**, and the trenches **264**. The fingers **420** can engage outer surfaces of each recess to resist forces attempting to pull the top collector plate **400** apart from the top frame **104** once it has been engaged. Optionally, inserts **253** can be installed into the mounting holes **412** and through holes **251**.

[0085] At step **506**, the bottom collector plate **300** is coupled to the bottom frame **106**. The bottom collector plate **300** is first positioned below the bottom frame **106**, then urged upward until the base **304** of the bottom collector plate **300** engages the bottom surface **154** of the bottom frame **106**. Alternatively, the CMA **100** can be flipped upside down, and the bottom collector plate **300** can be positioned above the bottom frame **106**, then urged downward until the base **304** of the bottom collector plate **300** engages the bottom surface **154** of the bottom frame. Once properly seated upon the bottom frame **106**, locating features **156**, **158** extend through each aperture **302**, ridges **308** extend into and engage each groove **157** in the bottom frame **106**, and supports **166** extend through each hole **316**. Fingers **320** of the bottom collector plate **300** extend upwardly (or downwardly, if the CMA **100** has been flipped) into recesses in the bottom frame **106**, including the mounting holes **160**, the channels **162**, and the trenches **164**. The fingers **320** can engage outer surfaces of each recess to resist any removing the bottom collector plate **300** from the bottom frame **106** once the components are engaged. Although steps **504** and **506** are described as happening in succession, step **506** and even steps **508** and **510**, discussed below, can occur prior to step **504**.

[0086] At step **508**, adhesive is applied to the CMA **100** to rigidly couple the bottom collector plate **300** and the bottom frame **106** to each battery cell **102** in the CMA **100**. Before applying adhesive, the frames **104**, **106** can be clamped together using the compression limiters **460**. Adhesive (e.g., glue) can first be applied to the top collector plate **400**. If the CMA **100** remains upside down, adhesive is first applied to the bottom collector plate **300** above each recess (e.g., mounting holes **160**, channels **162**, trenches **164**) formed in the bottom frame **106**. The fingers **320** extending into each recess can separate and shape the adhesive flow inward, into the pockets **112** and onto the

battery cells **102** received in the pockets **112**. The positioning of the recesses directs adhesive into each pocket **112** and toward each battery cell **102** in at least two (and in some cases three) directions, each of which are spaced apart from one another angularly about each battery cell **102** by at least about 90 degrees. The angle of adhesive introduction can be different depending on the location of the battery cell **102** within the array. The adhesive can be introduced into the pockets **112** in directions approximately normal to each battery cell **102**. The adhesive continues to flow downward, through the recesses and along the outer surfaces of the battery cells **102**.

[0087] At step **510**, the adhesive is cured. In some embodiments, the adhesive can be cured by exposing the CMA to ultraviolet (UV) light for a predetermined time period. The adhesive, generally, can be a glue or epoxy that sets or cures rapidly when exposed to stimuli, such as UV light, ozone gas, or other reactants. Once the adhesive has cured, rigid couplings are formed between each of the bottom collector plate **300** and the bottom frame **106** and the bottom frame **106** and each battery cell **102**. The rotational orientation of each battery cell **102** is rigid and secured by the at least two points of adhesive contact formed on each end of the battery cell **102**.

[0088] At step **512**, the CMA **100** is flipped over, such that the top frame **104** and top collector plate **400** face upward. Adhesive can then be applied to the top collector plate **400**. In some embodiments, adhesive is applied to the top collector plate **400** above each recess (e.g., mounting holes **260**, channels **262**, trenches **264**) formed in the top frame **104**. The fingers **420** extending into each recess can separate and shape the adhesive flow inward, into the pockets **212** and onto the battery cells **102** received in the pockets **212**, along the adhesive flow paths **430** shown in FIGS. 7D-7I. The positioning of the recesses directs adhesive into each pocket **212** and toward each battery cell **102** in at least two directions, each of which are spaced apart from one another angularly about each battery cell **102** by at least about 90 degrees. The angle of adhesive introduction can be different depending on the location of the battery cell **102** within the array. The adhesive can be introduced into the pockets **212** in directions approximately normal to each battery cell **102**. The adhesive continues to flow downward, through the recesses and along the outer surfaces of the battery cells **102**.

[0089] FIGS. 7H and 7I depict the adhesive path **430** through mounting holes **260** that creates multiple points of adhesive contact with each battery cell **102**. Adhesive is supplied to the top collector plate **400** above each recess in the top frame **104**, including each mounting hole **260**. As the adhesive approaches the top frame **104**, it can first be contacted by the one or more fingers **420** extending from the top collector plate **400** into the mounting hole **260**. The fingers **420** shape the adhesive flow by directing flow outward, toward the battery cells **102** positioned on either side of the finger **420**. The windows **220** formed in each cylindrical protrusion **210** create a flow path for adhesive to travel toward and into each pocket **212** to contact the battery cell **102**. Adhesive within the mounting hole **260** can then contact each of the battery cell **102**, top frame **104**, and top collector plate **400** (at the finger **420**, for example) simultaneously. The fingers **420** can be enlarged or angled to provide additional anchoring of the top collector plate **400** to the top frame **104**. As multiple (at least two, and sometimes three) windows **220** exist in each pocket, every battery cell is contacted by adhesive in at least two different directions, each of which are at least 45 degrees and preferably 90 degrees offset from one another.

[0090] At step **514**, the adhesive is cured. Once again, the adhesive can be cured by exposing the CMA to ultraviolet (UV) light for a predetermined time period. The adhesive, generally, can be a glue or epoxy that sets or cures rapidly when exposed to stimuli, such as UV light, ozone gas, or other reactants. Once the adhesive has cured in step **514**, rigid couplings are formed between each of the bottom collector plate **300** and the bottom frame **106** and the bottom frame **106** and each battery cell **102**. The rotational orientation of each battery cell **102** is rigid and secured by the at least two points of adhesive contact formed on each end of the battery cell **102**. The layout of each frame **104**, **106**, collector plate **300**, **400**, and battery cell **102** produces a CMA **100** that can be built entirely without metal fasteners. Fasteners can create numerous problems during conventional

battery assembly when they are dropped between battery cells or make electrical contact with other current conducting features, and eliminating the need for fasteners within battery assemblies can improve assembly efficiency.

[0091] Once the adhesive has cured, electrical connections can be made within the CMA **100**. For example, each terminal **103** of the conducting wires **107** can be coupled to a battery cell **102** and each terminal **109** can be coupled to the top collector plate **400** using wire bonding. Similarly, each terminal **105** can be coupled to the bottom collector plate **300** and each terminal **111** can be coupled to a battery cell **102** using wire bonding. The terminal connections can occur within troughs **322**, **422** formed behind each ridge **308**, **408** in the collector plates **300**, **400**. The troughs **322**, **422** can be sunken into the collector plates **300**, **400**. In some embodiments, two terminals **103**, **105** are coupled to the collector plate **300**, **400** within a common trough **322**, **422**, as shown in FIG. 7D. The troughs **322**, **422**, along with the locating features **156**, **158**, **256**, **258** surround and protect the terminals **103**, **105** from damage. The troughs **322**, **422** also reduce the amount of bending needed to couple each terminal **103**, **105** to the collector plates **300**, **400**, which improves battery efficiency by reducing the amount of resistance in each terminal **103**, **105** and allowing more current to pass through each terminal **103**, **105**. In some embodiments, a chemical fuse or a semiconductor fuse **450**, shown in FIG. 7C, can be coupled to the CMA **100** to provide additional safety in the event of a short circuit. The fuse **450** is selected so that it breaks the electrical circuit at a fuse threshold current below a wire bond threshold current, so that the fuse **450** is activated and breaks the electrical circuit before the wire bonds melt or otherwise fail due to an overcurrent condition. The controller **440** including the BMS can also be coupled to at least one of the battery cells **102** in the CMA **100** (e.g., with one of the collector plates **300**, **400** or one of the inserts **253**). The CMA **100** can then be used individually or in a battery pack to provide electrical power to a vehicle or other equipment.

[0092] Once the CMA **100** is fully assembled, a battery pack **600** of several CMAs **100** can be created. As shown in FIG. 9, mating tabs **172**, **272** and mating notches **174**, **274** formed on each of the top frames **104** and the bottom frames **106** can be coupled together to create a battery pack **600**. As shown, CMAs **100** can be coupled together on all four sides of the CMA **100**, which allows for unique battery pack builds suitable for specific applications. CMAs **100** can also be stacked vertically, where supports **166**, **266** and collars **122**, **124**, **222**, **224** engage and support one another on adjacent CMAs **100**. The spacers **144**, **244** that can be present in each of the top frame **104** and bottom frame **106** can improve airflow within the battery pack **600**, which may prevent overheating. Each CMA **100** can be electrically combined with additional CMAs **100** by using conductors extending between top or bottom collector plates **400**, **300** of adjacent batteries. In some examples, each bottom collector plate **300** is electrically coupled to a negative bus (not shown) while each top collector plate **400** is electrically coupled to at least one adjacent CMA **100**. At least one of the CMAs **100** in the battery pack **600** can include a conductor outputting electrical power to a vehicle, a system, or equipment.

[0093] The modular mating features of the CMAs **100** enable users to customize a battery pack suitable for a particular end use. The number of CMAs **100** needed, how the CMAs **100** are connected to each other, and the available physical space (e.g., volume or footprint) for the battery pack can all be factored in to design a customized battery pack that can be built substantially cheaper than current methods allow. The CMA **100** can serve as a single unit “building block” for assembling battery packs with different ratings and of different sizes for use in particular applications. This flexibility allows a battery pack to be customized for its particular application while using the same CMA building block across multiple battery pack applications. Each battery pack may be identified with an individual identifier (e.g., serial number, bar code, etc.) for use by the CMA manufacturer to track, categorize, evaluate, or record information or data about an individual battery pack and the particular CMAs used in that battery pack.

[0094] As utilized herein, the terms “approximately,” “about,” “substantially,” and similar terms

are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the disclosure as recited in the appended claims. It should be noted that the term “exemplary” and variations thereof, as used herein to describe various embodiments, are intended to indicate that such embodiments are possible examples, representations, or illustrations of possible embodiments (and such terms are not intended to connote that such embodiments are necessarily extraordinary or superlative examples). The term “coupled” and variations thereof, as used herein, means the joining of two members directly or indirectly to one another. Such joining may be stationary (e.g., permanent or fixed) or moveable (e.g., removable or releasable). Such joining may be achieved with the two members coupled directly to each other, with the two members coupled to each other using a separate intervening member and any additional intermediate members coupled with one another, or with the two members coupled to each other using an intervening member that is integrally formed as a single unitary body with one of the two members. If “coupled” or variations thereof are modified by an additional term (e.g., directly coupled), the generic definition of “coupled” provided above is modified by the plain language meaning of the additional term (e.g., “directly coupled” means the joining of two members without any separate intervening member), resulting in a narrower definition than the generic definition of “coupled” provided above. Such coupling may be mechanical, electrical, or fluidic. References herein to the positions of elements (e.g., “top,” “bottom,” “above,” “below”) are merely used to describe the orientation of various elements in the FIGURES. It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

[0095] The hardware and data processing components used to implement the various processes, operations, illustrative logics, logical blocks, modules and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some embodiments, particular processes and methods may be performed by circuitry that is specific to a given function. The memory (e.g., memory, memory unit, storage device) may include one or more devices (e.g., RAM, ROM, Flash memory, hard disk storage) for storing data and/or computer code for completing or facilitating the various processes, layers and modules described in the present disclosure. The memory may be or include volatile memory or non-volatile memory, and may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. According to an exemplary embodiment, the memory is communicably connected to the processor via a processing circuit and includes computer code for executing (e.g., by the processing circuit or the processor) the one or more processes described herein. The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure may be implemented using existing computer processors, or

by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

Claims

1. A cell module assembly, comprising: a first frame including a first plurality of pockets; a second frame spaced apart from the first frame and including a second plurality of pockets; a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets; a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame by a first curable adhesive; and a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame by a second curable adhesive.
2. The cell module assembly of claim 1, wherein each of the first plurality of pockets includes a protrusion extending outwardly relative to a first surface of the first frame.
3. The cell module assembly of claim 2, wherein the first plurality of pockets each define a recess that extends inwardly into a second surface of the first frame, the first surface being opposite to the second surface.
4. The cell module assembly of claim 1, wherein the first frame includes a plurality of mounting holes that each extend through the first frame and connect two adjacent pockets in the first plurality of pockets.
5. The cell module assembly of claim 4, wherein the plurality of mounting holes define a plurality of windows in each of the first plurality of pockets.
6. The cell module assembly of claim 5, wherein the first curable adhesive extends through the plurality of windows to contact each of the plurality of lithium-ion battery cells in at least two separate locations.
7. The cell module assembly of claim 6, wherein the at least two separate locations are circumferentially offset from one another.
8. The cell module assembly of claim 1, wherein the first frame includes a first collar formed on an outer perimeter of the first frame and the second frame includes a second collar formed on an outer perimeter of the second frame.
9. The cell module assembly of claim 8, wherein a compression rod is received within and extends between the first collar and the second collar.
10. The cell module assembly of claim 1, wherein the first frame includes an outer perimeter having one or more mating tabs extending outwardly from the outer perimeter and one or more mating notches extending inwardly into the outer perimeter.
11. A cell module assembly, comprising: a first frame defining a first plurality of pockets, the first frame including a first collar extending outwardly from an outer perimeter of the first frame, a

protrusion extending outwardly from the outer perimeter of the first frame, and a recess extending inwardly into the outer perimeter of the first frame; a second frame spaced apart from the first frame and defining a second plurality of pockets, the second frame including a second collar extending outwardly from an outer perimeter of the second frame, the first collar being axially aligned with the second collar; a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets; a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame; a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame; and a compression rod received within and extending between the first collar and the second collar.

12. The cell module assembly of claim 11, wherein a third collar is formed on the outer perimeter of the first frame opposite the first collar, and wherein a fourth collar is formed on the outer perimeter of the second frame opposite the second collar, the third collar and the fourth collar being axially aligned and receiving a second compression rod extending therebetween.

13. The cell module assembly of claim 11, wherein the compression rod defines an axial height that is larger than an axial height defined by the plurality of lithium-ion battery cells.

14. The cell module assembly of claim 11, wherein the compression rod defines a diameter smaller than a diameter of the plurality of lithium-ion battery cells.

15. The cell module assembly of claim 11, wherein the first frame includes a plurality of mounting holes that each extend through the first frame and connect two adjacent pockets in the first plurality of pockets, and wherein a curable adhesive is arranged within and extends through the plurality of mounting holes to contact each of the plurality of lithium-ion battery cells in at least two separate locations.

16. A cell module assembly, comprising: a first frame defining a first plurality of pockets, the first frame including an outer perimeter having one or more mating tabs extending outwardly from the outer perimeter and one or more mating notches extending inwardly into the outer perimeter; a second frame spaced apart from the first frame and defining a second plurality of pockets; a plurality of lithium-ion battery cells coupled to and extending between the second frame and the first frame, each one of the plurality of lithium-ion battery cells is received within a respective one of the first plurality of pockets and a respective one of the second plurality of pockets; a first collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the first frame; and a second collector plate electrically connected to the plurality of lithium-ion battery cells and coupled to the second frame.

17. The cell module assembly of claim 16, wherein the first frame includes a plurality of mounting holes that each extend through the first frame and connect two adjacent pockets in the first plurality of pockets, and wherein a curable adhesive is arranged within and extends through the plurality of mounting holes to contact each of the plurality of lithium-ion battery cells in at least two separate locations.

18. The cell module assembly of claim 16, wherein the one or more mating tabs and the one or more mating notches are complimentary.

19. The cell module assembly of claim 16, wherein an outer perimeter of the second frame includes one or more mating tabs extending outwardly from the outer perimeter and one or more mating notches extending inwardly into the outer perimeter.

20. The cell module assembly of claim 16, wherein each of the one or more mating tabs tapers outwardly as it extends away from the outer perimeter of the first frame.
