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Inventor(s)	Steinmetz; Andrew Douglas et al.

COMPRESSION PADS FOR BATTERY MODULES

Abstract

A compression pad for pressurizing an outer surface of at least one energy storage cell is disclosed. The at least one energy storage cell exhibits alternating high-pressure and low-pressure regions across the outer surface under a loading. The compression pad includes a body that defines a corrugated surface. The corrugated surface includes alternating protrusion portions and depression portions. The corrugated surface contacts the outer surface and aligns with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

Inventors: **Steinmetz; Andrew Douglas (Mapleton, IL), Pham; Hiep Thi-Ngoc (Pekin, IL)**

Applicant: **Caterpillar Inc.** (Peoria, IL)

Family ID: **96660131**

Assignee: **Caterpillar Inc. (Peoria, IL)**

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to battery modules in work machines. More particularly, the present disclosure relates to a compression pad for controlling pressure distribution across outer surfaces of at least one energy storage cell stored within a battery module.

BACKGROUND

[0002] Work machines, such as wheel loaders and the like machines, are generally equipped with battery modules for powering operations of the work machines. A battery module typically includes a housing and multiple energy storage cells, such as lithium-ion prismatic (or pouch) cells. The energy storage cells are generally stacked side-by-side (i.e., a face of one energy storage cell is adjacent to a face of another energy storage cell) within the housing.

[0003] The energy storage cells stacked within the housing are compressed (pressurized, or preloaded) together, for example, via flat end plates of the housing, to secure the energy storage cells therewithin and/or to ensure ideal performance and life of the energy storage cells. As the energy storage cells tend to swell over their useable life, for example, due to temperature, age, state of a charge, or charging and discharging of the energy storage cells, it may be difficult to compress the energy storage cells uniformly across surfaces of the energy storage cells.

[0004] Chinese patent no. 213,278,241 discloses a magnesium power generation device. The magnesium power generation device includes a shell and a battery core assembly fixedly arranged in the shell. The battery core assembly includes a battery core and elastic buffer layers. The battery core includes a metal copper plate, a catalytic layer, a water absorbing layer, and a metal magnesium plate stacked in sequence. The elastic buffer layers are fixedly arranged on upper surface and lower surface of the battery core and a gap is formed between the elastic buffer layer and at least one inner wall surface of the shell.

SUMMARY OF THE INVENTION

[0005] In one aspect, the disclosure relates to a compression pad for pressurizing an outer surface of at least one energy storage cell. The at least one energy storage cell exhibits alternating high-pressure and low-pressure regions across the outer surface under a loading. The compression pad includes a body that defines a corrugated surface. The corrugated surface includes alternating protrusion portions and depression portions. The corrugated surface is configured to contact the outer surface and align with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

[0006] In another aspect, the disclosure is directed to a battery module for a work machine. The battery module includes a housing, at least one energy storage cell, and a compression pad. The at least one energy storage cell is disposed within the housing. The at least one energy storage cell defines an outer surface and exhibits alternating high-pressure and low-pressure regions across the outer surface under a loading. The compression pad is configured to pressurize the outer surface of the at least one energy storage cell under the loading. The compression pad includes a body. The body defines a corrugated surface. The corrugated surface includes alternating protrusion portions and depression portions. The corrugated surface is configured to contact the outer surface and align with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

[0007] In yet another aspect, the disclosure relates to a method for controlling pressure distribution across an outer surface of at least one energy storage cell of a battery module. The at least one energy storage cell exhibits alternating high-pressure and low-pressure regions across the outer surface under a loading. The method includes positioning a compression pad within the battery module. The compression pad includes a body. The body defines a corrugated surface. The corrugated surface includes alternating protrusion portions and depression portions. The compression pad is positioned in a way that the corrugated surface contacts the outer surface and aligns with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] FIG. **1** is a side view of an exemplary work machine including a battery module, in accordance with an embodiment of the present disclosure;
[0009] FIG. **2** is a perspective view of the battery module including a housing and multiple energy storage cells packed within the housing, in accordance with an embodiment of the present disclosure;
[0010] FIG. **3** is a side exploded view of the battery module, with a side plate of the housing of the battery module removed, in accordance with an embodiment of the present disclosure;
[0011] FIG. **4** is a side view of a first compression pad disposed within the battery module, in accordance with an embodiment of the present disclosure;
[0012] FIG. **5** is an exploded view of a portion of the battery module depicting the first compression pad disposed between two neighboring energy storage cells of the battery module, in accordance with an embodiment of the present disclosure;
[0013] FIG. **6** is a side view of a second compression pad disposed within the battery module, in accordance with an embodiment of the present disclosure; and
[0014] FIG. **7** is an exploded view of a portion of the battery module depicting the second compression pad disposed between an energy storage cell and a flat end plate of the housing, in accordance with an embodiment of the present disclosure; and
[0015] FIG. **8** illustrates an exemplary pressure distributions across an outer surface of the energy storage cell compressed under a loading within the battery module, in accordance with an embodiment of the present disclosure.
DETAILED DESCRIPTION
[0016] Reference will now be made in detail to specific embodiments or features, examples of which are illustrated in the accompanying drawings. Generally, corresponding reference numbers may be used throughout the drawings to refer to the same or corresponding parts, e.g., 1, 1′, 1″, 101 and 201 could refer to one or more comparable components used in the same and/or different depicted embodiments.
[0017] Referring to FIG. **1**, a machine **100** is illustrated. As exemplarily depicted, the machine **100** includes a loader machine, such as a wheel loader **100**′. However, it may be contemplated that the machine **100** may be of any type which may be configured to perform operations associated with an industry, such as, mining, construction, farming, and transportation. An application of one or more aspects of the present disclosure may be extended to stationary machines, such as generator sets, as well. Therefore, it will be appreciated that references to the machine **100** is exemplary. Other examples of machine **100** may include, but are not limited to, an off-highway truck, an articulated truck, a paver, an excavator, a backhoe loader, a skid steer loader, a compactor. As shown in FIG. **1**, the machine **100** includes ground engaging members **104** (such as, wheels **104**),

an implement **108** (such as, a bucket **108′**), and a pair of movable lift arms **112** that may be applied to manipulate the implement **108**.

[0018] The machine **100** may include a power source **116** that may provide power to operate the machine **100**. The power source **116** may include one or more battery modules, such as a battery module **120** (shown in FIG. **2**). In an example, the battery module **120** may supply power to the ground engaging members **104**, for example, to move the machine **100** over a ground surface **124**. The battery module **120** may also be used to supply power to operate the implement **108** and perform various other operations of the machine **100**. In some embodiments, the battery module **120** may work in conjunction with one or more additional power sources (not shown), such as an internal combustion engine, an electric generator, a turbine, or any other suitable device, by which power may be produced and then supplied to perform one or more of the operations of the machine **100**.

[0019] Referring to FIGS. **2** and **3**, the battery module **120** is discussed. The battery module **120** includes a housing **128** and multiple energy storage cells **132** (discussed below). The battery module **120** may also include electrical and/or electronic components, such as busbars, a battery management system, and the like. It should be noted that construction and functionality of such electrical and/or electronic components are known in the art, and therefore, they are not discussed.

[0020] The housing **128** may be embodied as a substantially cuboid shaped structure **136**. The cuboid shaped structure **136** may be formed of multiple plates, namely—a pair of side plates (i.e., a first side plate **140**, and a second side plate **144**, shown in FIG. **5**), a pair of end plates (i.e., a first end plate **148**, and a second end plate **152**), and a base plate **156**. The first side plate **140** and the second side plate **144** may extend parallel to one another. In addition, the first side plate **140** and the second side plate **144** may extend at an angle from the base plate **156**, for example, upright with respect to the base plate **156**, to define respective sides of the housing **128**.

[0021] The first end plate **148** and the second end plate **152** may extend parallel to one another. In addition, the first end plate **148** and the second end plate **152** may extend upright with respect to the base plate **156**. Furthermore, the first end plate **148** and the second end plate **152** may be coupled to respective ends of the first side plate **140** and the second side plate **144** to define respective ends of the housing **128**. In some embodiments, the first end plate **148** and the second end plate **152** may be flat end plates. The first side plate **140**, the second side plate **144**, the first end plate **148**, the second end plate **152**, and the base plate **156** may be arranged (or coupled) together to define and surround an interior volume **160** (shown in FIG. **5**) of the housing **128**. Alternatively, in other embodiments, the base plate **156** may be omitted.

[0022] For explanatory purposes, at least one energy storage cell, for example, an energy storage cell **164** of the energy storage cells **132**, will now be explained in detail with reference to FIGS. **2** and **3**. However, it should be noted that the description provided below for the energy storage cell **164** is equally applicable to the other energy storage cells **132** of the battery module **120** without any limitations.

[0023] The energy storage cell **164** may be a prismatic cell **164′**. Alternatively, in other embodiments, the energy storage cell **164** may be a pouch cell. Further, the energy storage cell **164** (or the prismatic cell **164**) may be an electrochemical cell. Examples of the electrochemical cell may include, but need not be limited to, a lithium-ion cell, such as, a lithium cobalt oxide cell, a lithium manganese oxide cell, a lithium nickel manganese cobalt oxide cell, a lithium iron phosphate cell, a lithium nickel cobalt aluminum oxide cell, and a lithium titanate cell.

[0024] The energy storage cell **164** includes a casing **168**. Referring to FIGS. **2**, **3** and **5**, the casing **168** is a cuboid shaped structure **168′** that defines six outer surfaces, namely—a first outer surface **172**, a second outer surface **176**, a third outer surface **180**, a fourth outer surface **184**, a fifth outer surface **188**, and a sixth outer surface **192**. The first outer surface **172** and the second outer surface **176** are relatively larger sides of the casing **168**. The first outer surface **172** and the second outer surface **176** may extend parallel to one another. The third outer surface **180**, the fourth outer surface

184, the fifth outer surface **188**, and the sixth outer surface **192** are relatively shorter sides of the casing **168**. The third outer surface **180** and the fourth outer surface **184** may be parallel to one another. The third outer surface **180** and the fourth outer surface **184** may extend between the first outer surface **172** and the second outer surface **176** to connect the first outer surface **172** with the second outer surface **176**. The fifth outer surface **188** and the sixth outer surface **192** may be parallel to one another. The fifth outer surface **188** and the sixth outer surface **192** may extend between the first outer surface **172** and the second outer surface **176** to connect the first outer surface **172** with the second outer surface **176**. In addition, the fifth outer surface **188** and the sixth outer surface **192** may extend between the third outer surface **180** and the fourth outer surface **184** to connect the third outer surface **180** with the fourth outer surface **184**.

[0025] Further, the energy storage cell **164** may include one or more electrical tabs **194** (e.g., a positive electrical tab **194′** and a negative electrical tab **194″**) for electrically connecting the energy storage cell **164** either with the other energy storage cells **132** of the battery module **120**, or with an external electrical circuit(s). In addition, the energy storage cell **164** may include other cell components enclosed within the casing **168**. Examples of these cell components include, but may not be limited to, electrodes, separators, and electrolytes. Structures and configurations of these cell components are well known in the art, and therefore, are not discussed.

[0026] The energy storage cells **132** are disposed in the interior volume **160** of the housing **128**. In an example, as shown in FIGS. **2** and **3**, the energy storage cells **132** are disposed side-by-side in a row (i.e., collectively referred to as a stack **134**) within the housing **128** such that a first outer surface **172** of one energy storage cell **132** faces a second outer surface **176** of another energy storage cell **132** within the housing **128**. Also, in such an arrangement, the first and second outer surfaces **172**, **176** of each of the energy storage cells **132** may be parallel to the first end plate **148** and the second end plate **152** of the housing **128**. In other embodiments, the housing **128** may accommodate multiple stacks of the energy storage cells **132** (such as the stack **134**) arranged in rows and columns.

[0027] The energy storage cells **132** disposed within the housing **128** are compressed (pressurized, or preloaded) together under a loading. In an example, at least one flat end plates (i.e., the first end plate **148** and the second end plate **152**) of the housing **128** may impart the loading on the energy storage cells **132** to compress the energy storage cells **132**. However, it is observed that the energy storage cells **132** are not uniformly pressurized, when compressed under such loading. That is, each of the energy storage cells **132** exhibits alternating high-pressure and low-pressure regions (i.e., a natural frequency of pressure distribution, shown as **195** in FIG. **8**) across its outer surfaces, when compressed under the loading. For instance, as shown in FIGS. **5** and **8**, the energy storage cell **132** (or the energy storage cell **164**) exhibits alternating high pressure regions **196** and low-pressure regions **198** across a length ‘l’ of the first outer surface **172** under the loading. Similar to the alternating high-pressure regions **196** and the low-pressure regions **198** across its first outer surface **172**, the energy storage cell **132** also exhibits alternating high pressure and low-pressure regions (not shown) across its second outer surface **176** under the loading.

[0028] In some embodiments, the energy storage cell **132** (or the energy storage cell **164**) exhibits alternating high pressure regions **196** and low-pressure regions **198** across a width ‘w’ of the first outer surface **172** under the loading. In some other embodiments, the energy storage cell **132** (or the energy storage cell **164**) exhibits alternating high pressure regions **196** and low-pressure regions **198** across both the length ‘l’ and the width ‘w’ of the first outer surface **172** under the loading.

[0029] To uniformly pressurize the outer surfaces (i.e., the first outer surface **172** and the second outer surface **176**) of the energy storage cells **132** disposed within the housing **128** under the loading, in one or more aspects of the present disclosure, the battery module **120** is provided with one or more compression pads **200**. The compression pads **200** include one or more first compression pads **204**, each configured to be disposed in-between two neighboring energy storage cells **132**, as shown in FIGS. **3** and **5**. In addition, the compression pads **200** include one or more second compression pads **208** disposed in-between an outermost energy storage cell **132** (of the energy storage cells **132**) and the flat end plate (e.g., the first end plate **148**) of the housing **128**, as shown in FIGS. **3** and **7**.

[0030] For explanatory purposes, a first compression pad **212** (of the one or more first compression pads **204**) disposed in-between two neighboring energy storage cells **132**, for example, the energy storage cell **164** (hereinafter referred to as “first energy storage cell **164**”) and another energy storage cell **216** (hereinafter referred to as “second energy storage cell **216**”) will now be explained in detail with reference to FIGS. **4** and **5**. However, it should be noted that the description provided below for the first compression pad **212** is equally applicable to the other first compression pads **204** of the battery module **120**, without any limitations.

[0031] The first compression pad **212** includes a body **220**. The body **220** may be fabricated using foam, plastic, rubber, polymer, or any other suitable compressible and/or non-conductive material. In an exemplary embodiment, the body **220** is fabricated from polyurethane material. The body **220** defines a corrugated surface **224** (hereinafter referred to as “first corrugated surface **224**”). Also, the body **220** defines a second corrugated surface **228** opposite to the first corrugated surface **224**. Further, the body **220** defines two mutually opposing side surfaces, namely—a first side surface **232** and a second side surface **236** that are perpendicular to the first corrugated surface **224** and the second corrugated surface **228**. Furthermore, the body **220** defines two mutually opposing side surfaces, namely—a third side surface **240** and a fourth side surface **244** (shown in FIG. **5**) that are perpendicular to the first corrugated surface **224**, the second corrugated surface **228**, the first side surface **232**, and the second side surface **236**.

[0032] The first corrugated surface **224** includes alternating protrusion portions **248** (hereinafter referred to as “first protrusion portions **248**”) and depression portions **252** (hereinafter referred to as “first depression portions **252**”) defined across an expanse or a length ‘L**1**’ of the first corrugated surface **224**. It should be noted that the length ‘L**1**’ is defined between the first side surface **232** and the second side surface **236** of the body **220**. Each of the first protrusion portions **248** and the first depression portions **252** may extend longitudinally along a width ‘W**1**’ defined between the third side surface **240** and the fourth side surface **244**.

[0033] Each of the first protrusion portions **248** may define a first concavity ‘C**1**’ that faces towards the body **220** of the first compression pad **212**, and each of the first depression portions **252** may define a second concavity ‘C**2**’ that faces away from the body **220** of the first compression pad **212**. Further, the first protrusion portions **248** may define corresponding first crests **256** in a first plane ‘P**1**’, and the first depression portions **252** may define corresponding first troughs **260** in a second plane ‘P**2**’. In some embodiments, the first plane ‘P**1**’ and the second plane ‘P**2**’ are parallel to each other.

[0034] The first corrugated surface **224** is configured to contact the outer surface of the at least one energy storage cell **132**. In an example, as shown in FIG. **5**, the first corrugated surface **224** is configured to contact the first outer surface **172** of the first energy storage cell **164**, when the first compression pad **212** is disposed in-between the first energy storage cell **164** and the second energy storage cell **216**. The first corrugated surface **224** contacts the first outer surface **172** in a manner such that a frequency of alternating first protrusion portions **248** and the first depression portions **252** (of the first corrugated surface **224**) aligns with the natural frequency of pressure distribution **195** across the first outer surface **172**. For example, the first protrusion portions **248** and the first depression portions **252** (of the first corrugated surface **224**) are aligned, respectively, with the low-pressure regions **198** and the high-pressure regions **196** of the first outer surface **172**. Once aligned in this manner, the first protrusion portions **248** exert relatively higher loads correspondingly on the low-pressure regions **198** and the first depression portions **252** exert relatively lower loads correspondingly on the high-pressure regions **196**. By exerting relatively higher loads (via the first protrusion portions **248**) and relatively lower loads (via the first depression portions **252**), respectively, on the low-pressure regions **198** and the high-pressure regions **196** of the first outer surface **172**, the first compression pad **212** may uniformly pressurize the first outer surface **172** (of the energy storage cell **164**), under the loading. An exemplary uniform pressure distribution **195′** across the first outer surface **172** of the energy storage cell **164** generated by the application of the first compression pad **212** is disclosed in FIG. **8**. The exemplary uniform pressure distribution **195′** may correspond to an even pressure distribution (throughout the first outer surface **172**) in which a difference between highs and lows of the pressure distribution is relatively lower than that of the pressure distribution **195** observed without the application of the first compression pad **212**.

[0035] The second corrugated surface **228** includes alternating protrusion portions **264** (hereinafter referred to as "second protrusion portions **264**") and depression portions **268** (hereinafter referred to as "second depression portions **268**") defined across an expanse or a length 'L**2**' of the second corrugated surface **228**. It should be noted that the length 'L**2**' is defined between the first side surface **232** and the second side surface **236** of the body **220**, and hence, the length 'L**2**' is equal to the length 'L**1**' of the first corrugated surface **224**.

[0036] Each of the second protrusion portions **264** and the second depression portions **268** may extend longitudinally between the third side surface **240** and the fourth side surface **244**. Each of the second protrusion portions **264** may define a third concavity 'C**3**' that faces towards the body **220** of the first compression pad **212**, and each of the second depression portions **268** may define a fourth concavity 'C**4**' that faces away from the body **220** of the first compression pad **212**.

[0037] Further, the second protrusion portions **264** may define corresponding second crests **272** in a third plane 'P**3**', and the second depression portions **268** may define corresponding second troughs **276** in a fourth plane 'P**4**'. In some embodiments, the third plane 'P**3**' and the fourth plane 'P**4**' may be parallel to each other. In some further embodiments, the first plane 'P**1**', the second plane 'P**2**', the third plane 'P**3**', and the fourth plane 'P**4**' may be parallel to one another. Further, as shown in FIG. **4**, the second crests **272** of the second protrusion portions **264** correspondingly align with the first crests **256** of the first protrusion portions **248**, and the second troughs **276** of the second depression portions **268** correspondingly align with the first troughs **260** of the first depression portions **252**.

[0038] The second corrugated surface **228** is configured to contact a second outer surface **176′** (similar to the second outer surface **176** of the first energy storage cell **164**) of the second energy storage cell **216**, when the first compression pad **212** is disposed in-between the first energy storage cell **164** and the second energy storage cell **216**. The second corrugated surface **228** contacts the second outer surface **176′** in a manner such that a frequency of alternating second protrusion portions **264** and the second depression portions **268** (of the second corrugated surface **228**) aligns with a natural frequency of pressure distribution (not shown) (similar to the natural frequency of pressure distribution **195**) across the second outer surface **176′**. For example, the second protrusion portions **264** and the second depression portions **268** (of the second corrugated surface **228**) are aligned, respectively, with the low-pressure and high-pressure regions (not shown) of the second outer surface **176′**. Once aligned in this manner, the second protrusion portions **264** exert relatively higher loads correspondingly on the low-pressure regions and the second depression portions **268** exert relatively lower loads correspondingly on the high-pressure regions. By exerting relatively higher loads (via the second protrusion portions **264**) and relatively lower loads (via the second depression portions **268**), respectively, on the low-pressure regions and the high-pressure regions of the second outer surface **176′**, the first compression pad **212** uniformly pressurizes the second outer surface **176′** (of the second energy storage cell **216**).

[0039] Referring to FIGS. **3**, **6**, and **7**, the second compression pads **208** are discussed. In an exemplary embodiment, the battery module **120** is provided with two second compression pads **208**. For instance, as shown in FIG. **3**, one of the second compression pad **208** (e.g., a second compression pad **280**) is disposed between the first end plate **148** (of the housing **128**) and an outermost energy storage cell **284** (of the energy storage cells **132**) adjacent to the first end plate **148**, and the other of the second compression pad **208** (e.g., a second compression pad **288**) is disposed between the second end plate **152** (of the housing **128**) and an outermost energy storage cell **292** (of the energy storage cells **132**) adjacent to the second end plate **152**.

[0040] For explanatory purposes, the second compression pad **280** is discussed. However, it should be noted that the description provided below for the second compression pad **280** is equally applicable to the second compression pad **288** of the battery module **120** without any limitations. The second compression pad **280** may be similar in many respects to the first compression pad **212** but may differ from the first compression pad **212** in that one of the first corrugated surface **224** and the second corrugated surface **228** is omitted, and instead, a planar surface **296** is defined opposite to the other of the first corrugated surface **224** and the second corrugated surface **228**. In an exemplary embodiment, as shown in FIG. **6**, the second corrugated surface **228** of the second compression pad **280** is omitted and the planar surface **296** is defined opposite to the first corrugated surface **224**. The planar surface **296** is configured to face and contact a flat face **300** of the flat end plate, i.e., the first end plate **148**, of the housing **128**, when the second compression pad **280** is disposed in-between the outermost energy storage cell **284** and the first end plate **148** of the housing **128**.

INDUSTRIAL APPLICABILITY

[0041] Over the course of the useful life of these energy storage cells **132**, the energy storage cells **132** may swell or expand. Typically, each of the energy storage cells **132** will tend to bulge outward from its relatively larger surfaces, i.e., from the first outer surface **172** and the second outer surface **176**, for example, due to a relatively low resistance along the relatively larger surfaces of the energy storage cell **132**. Additionally, and/or alternatively, each of the energy storage cells **132** may swell outward from its relatively smaller surfaces, i.e., from at least one of the third outer surface **180**, the fourth outer surface **184**, the fifth outer surface **188**, and the sixth outer surface **192**. In some examples, the swelling in the relatively larger surfaces may be greater than the swelling in the relatively shorter surfaces of the energy storage cell **132**. Such swelling or expansion may be due to various factors. For example, the energy storage cells **132** may expand and/or contract as the energy storage cells **132** undergoes charging and discharging processes. In another example, the energy storage cells **132** may irreversibly swell based on chemical reactions occurring within the energy storage cells **132** due to charge and discharge over the battery life of the energy storage cells **132**.

[0042] To ensure ideal performance of the energy storage cells **132**, extend the battery life of the energy storage cells **132**, or slow the swelling of the energy storage cells **132**, the energy storage cells **132** disposed within the housing **128** of the battery module **120** are compressed (pressurized, or preloaded) together under a loading. In an example, at least one flat end plates (i.e., the first end plate **148**, the second end plate **152**) of the housing **128** may impart the loading on the energy storage cells **132** to compress the energy storage cells **132**. However, it is observed that each of these energy storage cells **132** (disposed within the housing **128**) exhibits alternating high-pressure and low-pressure regions (such as the high-pressure regions **196** and the low-pressure regions **198**) across its outer surfaces, i.e., the first outer surface **172** and the second outer surface **176**, when compressed under the loading. To uniformly pressurize the outer surfaces of each these energy storage cells **132** compressed within the housing **128**, in one or more aspects of the present disclosure, the battery module **120** is provided with the compression pads **200** (e.g., the first compression pads **204** and the second compression pads **208**).

[0043] An exemplary method of controlling pressure distribution across the outer surface (e.g., the first outer surface **172**) of at least one energy storage cell **132** (e.g., the first energy storage cell **164**) under the loading (e.g., preload exerted by at least one of the first end plate **148** and the second end plate **152**) is discussed. The method is discussed in conjunction with FIGS. **1-8**. The method includes positioning the compression pad **200** within the housing **128** of the battery module **120**. In an example, multiple compression pads **200** (e.g., the first compression pads **204** and the second compression pads **208**) may be positioned during assembling the battery module **120**. As shown in FIG. **3**, each of the first compression pads **204** is disposed in-between the two neighboring energy storage cells **132**. In addition, one of the second compression pad **208** (e.g., the second compression pad **280**) is disposed between the first end plate **148** (of the housing **128**) and the outermost energy storage cell **284** adjacent to the first end plate **148**, and the other of the second compression pad **208** (e.g., the second compression pad **288**) is disposed between the second end plate **152** (of the housing **128**) and the outermost energy storage cell **292** adjacent to the second end plate **152**.

[0044] The compression pad **200** (e.g., the first compression pad **204** and the second compression pad **208**) is positioned in a manner such that its corrugated surface (e.g., the first corrugated surface **224**) contacts the outer surface (e.g., the first outer surface **172**) of its adjacent energy storage cell **132** and aligns with the natural frequency of pressure distribution **195** (i.e., high-pressure regions **196** and low-pressure regions **198**) across the outer surface (of the energy storage cell **132**). Once aligned in this manner, the protrusion portions (e.g., the first protrusion portions **248**) of the compression pad **200** may exert relatively higher loads correspondingly on the low-pressure regions **198** and the depression portions (e.g., the first depression portions **252**) of the compression pad **200** may exert relatively lower loads correspondingly on the high-pressure regions **196**. By exerting relatively higher loads (via the protrusion portions) and relatively lower loads (via the depression portions), respectively, on the low-pressure regions **198** and the high-pressure regions **196** of the outer surface (e.g., the first outer surface **172**) of the energy storage cell **132**, the compression pad **200** uniformly pressurizes the outer surface of the energy storage cell **132** under the loading, as shown in FIG. **8**. By uniformly pressurizing the outer surfaces of each energy storage cell **132** using the compression pads **200**, performance of the energy storage cells **132** may be improved, battery life of the energy storage cells **132** may be extended, and/or the swelling of the energy storage cells **132** may be slowed.

[0045] In some embodiments, in which the energy storage cell **132** (or the energy storage cell **164**) exhibits vertical pressure variations, i.e., alternating high pressure regions and low-pressure regions across the width ‘w’ of the first outer surface **172** under the loading, the compression pad **212** may be positioned in a manner such its protrusion portions and the depression portions may, respectively, align with the high-pressure regions and the low-pressure regions across the width ‘w’ of the first outer surface **172**.

[0046] In other embodiments, the compression pad **212** may include a corrugated surface with alternating protrusion and depression portions defined in desired sizes and patterns to inversely mirror the observed natural frequency of pressure distributions on the outer surface (e.g., the first outer surface **172**) of the energy storage cell **132**. In an example, in which the energy storage cell **132** exhibits alternating high pressure regions and low-pressure regions across both the length ‘l’ and the width ‘w’ of the first outer surface **172** under the loading, the compression pad **212** having a corrugated surface with protrusion and depression portions arrayed alternately along both the length ‘L**1**’ and the width ‘W**1**’ of the corrugated surface may be selected.

[0047] In another example, the first plane ‘P**1**’ (on which the first crests **256** are defined), the second plane ‘P**2**’ (on which the first troughs **260** are defined), the third plane ‘P**3**’ (on which the second crests **272** are defined), and the fourth plane ‘P**4**’ (on which the second trough **276** are defined) may not be parallel to one another. In yet another example, the size (e.g., height, depth, width, etc.,) of the first protrusion portions **248** and the first depression portions may vary across at least one of the lengths ‘L**1**’ or ‘L**2**’ and/or the width ‘W**1**’ of the compression pad **212** based on variation in magnitude of the pressure observed across the outer surface (e.g., the first outer surface **172**) of the energy storage cell **132** under the loading.

[0048] Unless explicitly excluded, the use of the singular to describe a component, structure, or operation does not exclude the use of plural such components, structures, or operations or their equivalents. The use of the terms “a” and “an” and “the” and “at least one” or the term “one or more,” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term "at least one" followed by a list of one or more items (for example, "at least one of A and B" or one or more of A and B") is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B; A, A and B; A, B and B), unless otherwise indicated herein or clearly contradicted by context. Similarly, as used herein, the word "or" refers to any possible permutation of a set of items. For example, the phrase "A, B, or C" refers to at least one of A, B, C, or any combination thereof, such as any of: A; B; C; A and B; A and C; B and C; A, B, and C; or multiple of any item such as A and A; B, B, and C; A, A, B, C, and C; etc.

[0049] It will be apparent to those skilled in the art that various modifications and variations can be made to the compression pad, the battery module, and/or the method of the present disclosure without departing from the scope of the disclosure. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the compression pad, the battery module, and/or the method disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims and their equivalent.

Claims

1. A compression pad for pressurizing an outer surface of at least one energy storage cell exhibiting alternating high-pressure and low-pressure regions across the outer surface under a loading, the compression pad comprising: a body defining a corrugated surface including alternating protrusion portions and depression portions, wherein the corrugated surface is configured to contact the outer surface and align with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

2. The compression pad of claim 1, wherein the protrusion portions define corresponding first crests in a first plane and the depression portions define corresponding first troughs in a second plane.

3. The compression pad of claim 2, wherein the first plane and the second plane are parallel to each other.

4. The compression pad of claim 1, wherein the outer surface is a first outer surface, and the corrugated surface is a first corrugated surface including alternating first protrusion portions and first depression portions, and wherein: the body defines a second corrugated surface including alternating second protrusion portions and second depression portions, the second corrugated surface is defined opposite to the first corrugated surface to contact a second outer surface of another energy storage cell and align with a natural frequency of pressure distribution across the second outer surface to uniformly pressurize the second outer surface under the loading.

5. The compression pad of claim 4, wherein the second protrusion portions define corresponding second crests in a third plane and the second depression portions define corresponding second troughs in a fourth plane.

6. The compression pad of claim 5, wherein the third plane and the fourth plane are parallel to each other.

7. The compression pad of claim 5, wherein the first crests of the first protrusion portions correspondingly align with the second crests of the second protrusion portions, and wherein the first troughs of the first depression portions correspondingly align with the second troughs of the second depression portions.

8. The compression pad of claim 1, wherein the body defines a planar surface opposite to the corrugated surface, the planar surface is configured to face and contact a flat end plate of a housing accommodating the at least one energy storage cell under the loading.

9. The compression pad of claim 1, wherein the body is fabricated from polyurethane material.

10. A battery module for a work machine, the battery module comprising: a housing; at least one energy storage cell disposed within the housing, the at least one energy storage cell defining an outer surface and exhibiting alternating high-pressure and low-pressure regions across the outer surface under a loading; and a compression pad for pressurizing the outer surface under the loading, the compression pad including: a body defining a corrugated surface including alternating protrusion portions and depression portions, wherein the corrugated surface is configured to contact the outer surface and align with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

11. The battery module of claim 10, wherein the protrusion portions define corresponding first crests in a first plane and the depression portions define corresponding first troughs in a second plane, and wherein the first plane and the second plane are parallel to each other.

12. The battery module of claim 11, wherein the outer surface is a first outer surface, and the corrugated surface is a first corrugated surface including alternating first protrusion portions and first depression portions, and wherein: the body defines a second corrugated surface including alternating second protrusion portions and second depression portions, the second corrugated surface is defined opposite to the first corrugated surface to contact a second outer surface of another energy storage cell disposed within the housing and align with a natural frequency of pressure distribution across the second outer surface to uniformly pressurize the second outer surface under the loading.

13. The battery module of claim 12, wherein the second protrusion portions define corresponding second crests in a third plane and the second depression portions define corresponding second troughs in a fourth plane, and wherein the third plane and the fourth plane are parallel to each other.

14. The battery module of claim 13, wherein the first crests of the first protrusion portions correspondingly align with the second crests of the second protrusion portions, and wherein the first troughs of the first depression portions correspondingly align with the second troughs of the second depression portions.

15. The battery module of claim 10, wherein the housing defines a flat end plate, and wherein the body defines a planar surface opposite to the corrugated surface, the planar surface is configured to face and contact the flat end plate under the loading.

16. The battery module of claim 10, wherein the body of the compression pad is fabricated from polyurethane material.

17. The battery module of claim 10, wherein the at least one energy storage cell is one of a pouch cell or a prismatic cell.

18. A method for controlling pressure distribution across an outer surface of at least one energy storage cell of a battery module, the at least one energy storage cell exhibiting alternating high-pressure and low-pressure regions across the outer surface under a loading, the method comprising: positioning a compression pad within the battery module, the compression pad including a body defining a corrugated surface including alternating protrusion portions and depression portions, wherein the compression pad is positioned in a way that the corrugated surface contacts the outer surface and aligns with a natural frequency of pressure distribution across the outer surface such that the protrusion portions exert relatively higher loads correspondingly on the low-pressure regions and the depression portions exert relatively lower loads correspondingly on the high-pressure regions to uniformly pressurize the outer surface under the loading.

19. The method of claim 18, wherein the outer surface is a first outer surface, and the corrugated surface is a first corrugated surface including alternating first protrusion portions and first depression portions, wherein the body defines a second corrugated surface including alternating second protrusion portions and second depression portions, the second corrugated surface is defined opposite to the first corrugated surface, and wherein the compression pad is positioned such that the second corrugated surface contacts a second outer surface of another energy storage cell disposed within the housing and aligns with a natural frequency of pressure distribution across the second outer surface to uniformly pressurize the second outer surface under the loading.

20. The method of claim 18, wherein the battery module includes a housing configured to accommodate the at least one energy storage cell therein, the housing defines a flat end plate, wherein the body defines a planar surface opposite to the corrugated surface, and wherein the compression pad is positioned between the at least one energy storage cell and the flat end plate such that the planar surface faces and contacts the flat end plate under the loading.