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COMBINED MATERIAL HONEYCOMB CORE

Abstract

A combined material honeycomb core and methods of manufacture are presented. The combined material honeycomb core comprises a plurality of cells arranged in columns and rows formed of multiple materials, the multiple materials comprising a metallic material and either a second metallic material or a non-metallic material.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a Divisional of U.S. patent application Ser. No. 18/317,068, filed May 13, 2023, allowed Mar. 4, 2025, and entitled “Combined Material Honeycomb Core,” which is incorporated herein by reference in its entirety.

BACKGROUND INFORMATION
1. Field
[0002] The present disclosure relates generally to honeycomb cores and more specifically to manufacturing honeycomb cores with multiple materials.
2. Background
[0003] Honeycomb panels are used in manufacturing portions of aircraft and other platforms, such as trains, ships, buildings, or other platforms. Honeycomb cores are sandwiched between two facesheets to form honeycomb panels. Hollow honeycomb cores result in honeycomb panels having lower weight than solid panels. However, honeycomb panels can have limited mechanical properties.
[0004] Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues.
SUMMARY
[0005] An embodiment of the present disclosure provides a combined material honeycomb core. The combined material honeycomb core comprises a plurality of cells arranged in columns and rows formed of multiple materials, the multiple materials comprising a metallic material and either a second metallic material or a non-metallic material.
[0006] Another embodiment of the present disclosure provides a structural panel with a combined material honeycomb core. The structural panel comprises the combined material honeycomb core comprising a plurality of cells formed of multiple materials, a first facesheet adhered to a first face of the combined material honeycomb core, and a second facesheet adhered to a second face of the combined material honeycomb core. The multiple materials comprise a metallic material and either a second metallic material or a non-metallic material.
[0007] Yet another embodiment of the present disclosure provides a method of manufacturing a combined material honeycomb core. Adhesive lines are printed onto a sheet of a first material and a sheet of a second material. The sheet of the first material and the sheet of the second material are cut into portions. The portions are stacked to form a stack comprising the first material and the second material. The adhesive in the stack is cured to form an adhered stack. The adhered stack is expanded to form the combined material honeycomb core.
[0008] A further embodiment of the present disclosure provides a method of manufacturing a combined material honeycomb core. A plurality of sheets of a first material is corrugated to form a first plurality of sheets of corrugated material. A plurality of sheets of a second material is corrugated to form a second plurality of sheets of corrugated material. The first plurality of sheets of corrugated material and the second plurality of sheets of corrugated material are adhered to form a honeycomb having an array of cells. The adhesive is cured, joining the array of cells of the honeycomb to form the combined material honeycomb core.
[0009] A yet further embodiment of the present disclosure provides a method of manufacturing a combined material honeycomb core. Two materials are three-dimensionally printed to form a honeycomb having an array of cells, each cell of the array of cells comprising the two materials.
[0010] The features and functions can be achieved independently in various embodiments of the

present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

[0012] FIG. **1** is an illustration of an aircraft in accordance with an illustrative embodiment;

[0013] FIG. **2** is an illustration of a block diagram of a manufacturing environment in accordance with an illustrative embodiment;

[0014] FIG. **3** is an illustration of steps to form a combined material honeycomb core in a corrugation method in accordance with an illustrative embodiment;

[0015] FIG. **4** is an illustration of steps to form a combined material honeycomb core in an expansion method in accordance with an illustrative embodiment;

[0016] FIG. **5** is an illustration of an exploded view and an isometric view of a structural panel formed of a combined material honeycomb core in accordance with an illustrative embodiment;

[0017] FIG. **6** is a flowchart of a method of manufacturing a combined material honeycomb core in accordance with an illustrative embodiment;

[0018] FIG. **7** is a flowchart of a method of manufacturing a combined material honeycomb core in accordance with an illustrative embodiment;

[0019] FIG. **8** is a flowchart of a method of manufacturing a combined material honeycomb core in accordance with an illustrative embodiment;

[0020] FIG. **9** is an illustration of an aircraft manufacturing and service method in the form of a block diagram in accordance with an illustrative embodiment; and

[0021] FIG. **10** is an illustration of an aircraft in the form of a block diagram in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

[0022] Turning now to FIG. **1**, an illustration of an aircraft is depicted in accordance with an illustrative embodiment. Aircraft **100** has wing **102** and wing **104** attached to body **106**. Aircraft **100** includes engine **108** attached to wing **102** and engine **110** attached to wing **104**.

[0023] Body **106** has tail section **112**. Horizontal stabilizer **114**, horizontal stabilizer **116**, and vertical stabilizer **118** are attached to tail section **112** of body **106**.

[0024] Aircraft **100** is an example of an aircraft that can have panels with a combined material honeycomb core. For example, at least one of wing **102**, wing **104**, or body **106** can be formed of a combined material honeycomb core.

[0025] Turning now to FIG. **2**, an illustration of a block diagram of a manufacturing environment is depicted in accordance with an illustrative embodiment. Manufacturing environment **200** is an environment in which portions of aircraft **100** of FIG. **1** can be manufactured. Combined material honeycomb core **202** can be manufactured in manufacturing environment **200**. Combined material honeycomb core **202** comprises plurality of cells **204**. Plurality of cells **204** has any desirable shape. In some illustrative examples, each cell of plurality of cells **204** has the same shape. In other illustrative examples, plurality of cells **204** comprises a plurality of shapes. In some illustrative examples, plurality of cells **204** comprises at least one of triangular, square, hexagonal, or circular cells. Combined material honeycomb core **202** can be formed with any desirable cell size. In some illustrative examples, combined material honeycomb core **202** can instead be referred to as a

combined material cellular core.
[0026] Combined material honeycomb core **202** comprises plurality of cells **204** formed of multiple materials **206** and regularly arranged in array **243**. Multiple materials **206** comprises first metallic material **212** and either second metallic material **214** or non-metallic material **216**. Second metallic material **214** is different from first metallic material **212**.
[0027] Array **243** is an ordered arrangement of plurality of cells **204**. In some illustrative examples, array **243** can be referred to as a two-dimensional lattice. Array **243** includes plurality of cells **204** positioned such that multiple cells extend in each of the two dimensions. Array **243** can be described as a plurality of stacked rows of cells or a plurality of stacked layers of cells.
[0028] Each cell of plurality of cells **204** comprises first metallic material **212** and either second metallic material **214** or non-metallic material **216**. In some illustrative examples, first metallic material **212** comprises aluminum **218**, and second metallic material **214** is titanium **220**. In some illustrative examples, first metallic material **212** comprises aluminum **218**, and non-metallic material **216** comprises Nomex **222**.
[0029] Nomex **222** is a meta-aramid material. Although Nomex **222** is listed specifically, non-metallic material **216** can be any other desirable meta-aramid material.
[0030] In some illustrative examples, combined material honeycomb core **202** further comprises cured adhesive **242** joining plurality of cells **204**. Cured adhesive **242** takes the form of any desirable type of structural adhesive.
[0031] Cured adhesive **242** can take the form of at least one of epoxy liquid, epoxy paste, or film adhesives. Considerations in selecting a type of adhesive for joining combined material honeycomb core **202** include temperature exposure, acoustical absorption, moisture/humidity, heat transfer, or outgassing requirements.
[0032] In some illustrative examples, cured adhesive **242** is the same material as first layer of structural adhesive **228**. In some illustrative examples, cured adhesive **242** is the same material as second layer of structural adhesive **232**. In some illustrative examples, at least one of cured adhesive **242**, first layer of structural adhesive **228**, or second layer of structural adhesive **232** are formed of the same adhesive.
[0033] Considerations for joining at least one of honeycomb cores or structural panels include increasing corrosion/wear protection, mechanical properties including shear, tensile, compression, creep, impact, fatigue and peel. Strength of structural panel **223** will vary depending upon density of combined material honeycomb core **202**, toughness of adhesive, direction of peel, type of surface preparation, etc.
[0034] Structural epoxy adhesive systems feature the highest tensile strengths of all commercially available bonding agents. Resistance to moisture, fuels, oils, acids, bases, and many other aggressive chemicals is of a very high order over a wide temperature range. Structural epoxy adhesive systems can safely be operated at service temperatures from as high as 300° C. (572° F.) to cryogenic conditions. When bonding dissimilar metals, the epoxy adhesive bond also functions as protection against galvanic corrosion.
[0035] In some illustrative examples, structural panel **223** is manufactured with combined material honeycomb core **202**. Structural panel **223** with combined material honeycomb core **202** comprises combined material honeycomb core **202** comprising plurality of cells **204** formed of multiple materials, first facesheet **230**, and second facesheet **234**. The multiple materials comprise first metallic material **212** and either second metallic material **214** or non-metallic material **216**. First facesheet **230** is adhered to first face **224** of combined material honeycomb core **202**. Second facesheet **234** is adhered to second face **226** of combined material honeycomb core **202**.
[0036] In some illustrative examples, structural panel **223** is referred to as a honeycomb panel. In some illustrative examples, structural panel **223** is referred to as a honeycomb core panel. In some illustrative examples, structural panel **223** is referred to as a cellular core panel.
[0037] In some illustrative examples, first facesheet **230** and second facesheet **234** are formed of

different materials. In some illustrative examples, first facesheet **230** comprises a metallic material and second facesheet **234** comprises a composite material. In some illustrative examples, first facesheet **230** takes the form of metallic sheet **231**. In some illustrative examples, second facesheet **234** takes the form of composite sheet **235**.

[0038] In some illustrative examples, first layer of structural adhesive **228** is between first facesheet **230** and first face **224** of combined material honeycomb core **202**. In some illustrative examples, second layer of structural adhesive **232** is between second facesheet **234** and second face **226** of combined material honeycomb core **202**. In some illustrative examples, first layer of structural adhesive **228** and second layer of structural adhesive **232** are formed of a same adhesive material.

[0039] The illustrative examples provide combined material honeycomb cores for composite structures. The combined material honeycomb cores comprise multiple materials. In some illustrative examples, the combined material honeycomb cores comprise two different metals. When two metals are present, percentages of each metal can be adjusted to tailor material properties of the combined material honeycomb core. For example, percentages of first metallic material **212** and second metallic material **214** can be adjusted to tailor material properties of combined material honeycomb core **202**.

[0040] In some illustrative examples, combined material honeycomb core **202** comprises non-metallic material **216** and first metallic material **212** forming cell walls of combined material honeycomb core **202**. Non-metallic material **216** provides improved tension of combined material honeycomb core **202** while first metallic material **212** provides improved compression of combined material honeycomb core **202**. By combining first metallic material **212** and non-metallic material **216** into combined material honeycomb core **202**, combined material honeycomb core **202** can have tailored material properties.

[0041] Non-metallic material **216** comprises at least one of Nomex **222**, paper, aramid fiber, thermoplastic, PVC foam, polystyrene foam, PMI (polymethacrylimide) foam, styrene acrylonitrile (SAM) co-polymer foam, or other desirable polymeric foams. First metallic material **212** comprises at least one of aluminum **218**, titanium, aluminum alloys, titanium alloys, superalloys, or stainless steels. In some illustrative examples, combined material honeycomb core **202** can include more than one metallic material to modify or tailor material properties.

[0042] In some illustrative examples, each cell of combined material honeycomb core **202** is formed of both first metallic material **212** and non-metallic material **216**. In some illustrative examples, combined material honeycomb core **202** comprises alternating sheets of metallic material and non-metallic material. In some illustrative examples, the combined material honeycomb core comprises a combination of Nomex and aluminum. In some illustrative examples, the combined material honeycomb core comprises a combination of aluminum and titanium.

[0043] Forming combined material honeycomb core **202** of first material **208** and second material **210** having different material properties allows for tailoring physical properties of structural panel **223**. Improved properties can result from combining first material **208** and second material **210** to form combined material honeycomb core **202**.

[0044] Ratio **280** of first material **208** and second material **210** can be modified to change a value of material characteristic **276**. In some illustrative examples, desired value **278** of material characteristic **276** is determined. In some illustrative examples, ratio **280** of first material **208** and second material **210** within combined material honeycomb core **202** is set based on desired value **278** of material characteristic **276**. When combined material honeycomb core **202** comprises aluminum **218** and Nomex **222**, combined material honeycomb core **202** has improved properties for structural panel **223**. Material characteristic **276** can include at least one of weight, strength to weight ratio, volume density, compressive strength, shear strength, heat transfer, electrical shielding, insulation, fatigue strength, or any other desirable characteristic.

[0045] Combined material honeycomb core **202** provides improved properties over a single

material honeycomb core formed of either first metallic material **212** or second material **210**. In some illustrative examples, first material **208** is aluminum **218** and second material **210** is Nomex **222**. Combined material honeycomb core **202** with aluminum **218** and Nomex **222** is non-flammable. In some illustrative examples, combined material honeycomb core **202** with aluminum **218** and Nomex **222** does not drip or melt, and instead only carbonizes once the temperature limit is exceeded. Combined material honeycomb core **202** with aluminum **218** and Nomex **222** is inherently fire resistant up to **350** degrees Celsius.

[0046] Combined material honeycomb core **202** can be manufactured in any desirable fashion. In some illustrative examples, combined material honeycomb core **202** is formed using corrugation **238**. In corrugation **238**, sheets or plates are pressed into corrugated sheets by using gears. Then, the corrugated sheets that contain a certain shape are bonded one by one to make a whole structure, honeycomb **266**. The cavities (or cells) of honeycomb **266** will be formed between each two sheets. Curing **251** is performed on the structure at a temperature of up to 180° C. (356° F.). Corrugation **238** is applicable for both metal and Non-metallic honeycombs. A combination of adhesive film/liquid adhesive and a corrugation process affords a way of making honeycomb panels formed of multiple materials. A combination of adhesive film/liquid adhesive and a corrugation process affords a way of making honeycomb panels which have modifiable material characteristics.

[0047] For example, plurality of sheets **258** of first material **208** are sent through gears to form first plurality of sheets of corrugated material **262**. Plurality of sheets **260** of second material **210** are sent through gears to form second plurality of sheets of corrugated material **264**. First plurality of sheets of corrugated material **262** is adhered to second plurality of sheets of corrugated material **264** to form honeycomb **266** with array of cells **268**. Adhesive **267** is applied to first plurality of sheets of corrugated material **262** and second plurality of sheets of corrugated material **264** to form honeycomb **266**.

[0048] Curing **251** is performed on honeycomb **266** to cure adhesive **267**. Curing **251** is performed at a temperature of up to 180° C. (356° F.). Curing **251** honeycomb **266** forms combined material honeycomb core **202** with cured adhesive **242**.

[0049] In some illustrative examples, combined material honeycomb core **202** is formed using expansion **236**. In expansion **236**, sheet **244** of first material **208** is passed through a printer for lines of adhesive **248** to be printed. Although first material **208** is described as sheet **244**, in some other illustrative examples, first material **208** can be provided in a roll and may be described as a "foil".

[0050] In expansion **236**, sheet **246** of second material **210** is passed through a printer for lines of adhesive **250** to be printed. After adhesive **248** has been printed onto sheet **244** and adhesive **250** has been printed onto sheet **246**, sheet **244** and sheet **246** are cut into portions **252**. Portions **252** are stacked to form stack **254** comprising first material **208** and second material **210**. Curing **251** is performed on stack **254** to form adhered stack **256**. Adhered stack **256** is expanded to form combined material honeycomb core **202**.

[0051] In some illustrative examples, adhered stack **256** can be cut to a desired thickness. In some illustrative examples, adhered stack **256** can be cut into multiple thicknesses and expanded into multiple combined material honeycomb cores.

[0052] In some illustrative examples, prior to joining combined material honeycomb core **202** to first facesheet **230** and second facesheet **234**, surface treatment **270** is applied to portions of combined material honeycomb core **202** to aid adhesion. In some illustrative examples, prior to joining combined material honeycomb core **202** to first facesheet **230** and second facesheet **234**, surface treatment **270** is applied to portions of combined material honeycomb core **202** to increase adhesivity. Surface treatment **270** comprises at least one of chemical **272** treatment, mechanical **274** treatment, or any other desirable type of treatment to aid adhesion of combined material honeycomb core **202** to at least one of first facesheet **230** or second facesheet **234**.

[0053] In some illustrative examples, surface treatment **270** includes mechanical **274** treatment to

roughen a surface of at least one of first metallic material **212** or second metallic material **214** to increase adhesion of first layer of structural adhesive **228** or second layer of structural adhesive **232**. In some illustrative examples, surface treatment **270** includes chemical **272** treatment to roughen a surface of at least one of first metallic material **212** or second metallic material **214** to increase adhesion of first layer of structural adhesive **228** or second layer of structural adhesive **232**. In some illustrative examples, surface treatment **270** includes chemical **272** treatment to chemically modify a surface of at least one of first metallic material **212** or second metallic material **214** to increase adhesion of first layer of structural adhesive **228** or second layer of structural adhesive **232**.

[0054] Surface treatment **270** is applied to metallic materials for combined material honeycomb core **202**. In some illustrative examples, surface treatment **270** is applied to first material **208** prior to combining into combined material honeycomb core **202**. In some illustrative examples, surface treatment **270** is applied to combined material honeycomb core **202**.

[0055] In some illustrative examples, honeycomb **266** comprises only metallic materials and honeycomb **266** can have surface treatment **270** applied to honeycomb **266**. In some illustrative examples, first plurality of sheets of corrugated material **262** and second plurality of sheets of corrugated material **264** are formed of metallic materials. In some of these illustrative examples, surface treatment **270** can be applied to first plurality of sheets of corrugated material **262** and second plurality of sheets of corrugated material **264** prior to forming honeycomb **266**. In some illustrative examples, second plurality of sheets of corrugated material **264** is non-metallic, and surface treatment **270** is applied to first plurality of sheets of corrugated material **262** prior to combining with second plurality of sheets of corrugated material **264**.

[0056] When second material **210** is second metallic material **214**, surface treatment **270** can be applied to first material **208** and second material **210** during any stage of expansion **236**. In some illustrative examples, surface treatment **270** can be applied to any of sheet **244**, sheet **246**, portions **252**, stack **254**, or adhered stack **256**. When second material **210** is non-metallic material **216**, either sheet **244** or portions **252** receive surface treatment **270** prior to forming stack **254** of first material **208** and second material **210**.

[0057] In some illustrative examples, combined material honeycomb core **202** can be formed using three-dimensionally printing **281**. In some illustrative examples, three-dimensionally printing **281** first material **208** and second material **210** forms honeycomb **282**. In some illustrative examples, honeycomb **282** is cured to form combined material honeycomb core **202**. In some illustrative examples, three-dimensionally printing **281** first material **208** and second material **210** forms combined material honeycomb core **202** without curing **251**.

[0058] The illustration of manufacturing environment **200** in FIG. **2** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment. For example, in some illustrative examples, more than one material characteristic is modified to meet a desired value or a desired range by combination of first material **208** and second material **210** in combined material honeycomb core **202**.

[0059] As another example, although multiple materials **206** is depicted as having first material **208** and second material **210**, multiple materials **206** can have any desirable quantity of materials. In some illustrative examples, multiple materials **206** comprises more than two materials. In some illustrative examples, material characteristic **276** is modified by selecting more than two materials in multiple materials **206** and adjusting ratios of the more than two materials in multiple materials **206**.

[0060] Turning now to FIG. **3**, an illustration of steps to form a combined material honeycomb core

in a corrugation method is depicted in accordance with an illustrative embodiment. The steps illustrated in view **300** can be used to manufacture components of aircraft **100** of FIG. **1**. The steps illustrated in view **300** can be used in manufacturing environment **200** to form combined material honeycomb core **202** of FIG. **2** using corrugation **238**. Combined material honeycomb core **312** is a physical implementation of combined material honeycomb core **202** of FIG. **2**.

[0061] In the corrugation method, sheets **302** of material are sent through corrugating rollers **304** to form corrugated sheets. Although the material depicted in FIG. **3** is described as "sheets", sheets **302** may instead be referred to as "ribbons" in some illustrative examples. In some illustrative examples, the term "ribbons" may be used when a width of the material to be corrugated is short compared to the length of the material. Likewise, corrugated metallic sheet **306** and second corrugated sheet **308** can be referred to as a corrugated metallic ribbon and a second corrugated ribbon. Corrugated metallic sheet **306** is formed of a first metallic material. Second corrugated sheet **308** is formed of a second material selected from one of a second metallic material or a non-metallic material. The corrugated sheets are bonded together to form the combined material honeycomb cores. As depicted, corrugated metallic sheet **306** and second corrugated sheet **308** are adhered to form single honeycomb layer **310**. Single honeycomb layer **310** is adhered to other single honeycomb layers to form combined material honeycomb core **312**. After forming combined material honeycomb core **312**, combined material honeycomb core **312** can be joined to facesheets to form a structural panel, such as structural panel **500** of FIG. **5**.

[0062] Corrugated metallic sheet **306** is formed of any desirable metallic material. In some illustrative examples, corrugated metallic sheet **306** is formed of aluminum or an aluminum alloy. Second corrugated sheet **308** is formed of any desirable material. In some illustrative examples, second corrugated sheet **308** is formed of a non-metallic material. In some illustrative examples, second corrugated sheet **308** is formed of a second metallic material. In some illustrative examples, second corrugated sheet **308** is formed of Nomex. In some illustrative examples, second corrugated sheet **308** is formed of titanium. In some illustrative examples, corrugated metallic sheet **306** takes the form of a corrugated aluminum sheet and second corrugated sheet **308** takes the form of a corrugated titanium sheet.

[0063] In some illustrative examples, combined material honeycomb core **312** is formed of a first metallic material and a non-metallic material. In some illustrative examples, the corrugation method can be used to form combined material honeycomb core **312** of two different metallic materials.

[0064] In some illustrative examples, the combined material honeycomb cores are formed using an expansion method. Turning now to FIG. **4**, an illustration of steps to form a combined material honeycomb core in an expansion method is depicted in accordance with an illustrative embodiment. In the expansion method, sheets of material have adhesive lines printed, and the sheets are cut and stacked. The steps illustrated in view **405** can be used to manufacture components of aircraft **100** of FIG. **1**. The steps illustrated in view **405** can be used in manufacturing environment **200** to form combined material honeycomb core **202** of FIG. **2** using expansion **236**. Combined material honeycomb core **408** is a physical implementation of combined material honeycomb core **202** of FIG. **2**.

[0065] As depicted, first sheet **400** has adhesive **401** printed onto it. Second sheet **402** has adhesive **403** printed in a predetermined pattern. First sheet **400** and second sheet **402** are cut and then stacked to form stack **404**. In this illustrative example, portions of first sheet **400** and second sheet **402** can be alternated. Stack **404** is heated and pressed to form a block with cured adhesive bonding the sheets. As depicted, stack **404** is in heating chamber **406**. Afterwards, the block with cured adhesive is expanded to form combined material honeycomb core **408**.

[0066] First sheet **400** is formed of any desirable metallic material. In some illustrative examples, first sheet **400** is formed of aluminum or an aluminum alloy. Second sheet **402** is formed of any desirable material. First sheet **400** is formed of a first metallic material. Second sheet **402** is formed

of a second material selected from one of a second metallic material or a non-metallic material.
[0067] In some illustrative examples, second sheet **402** is formed of a non-metallic material. In some illustrative examples, second sheet **402** is formed of a second metallic material. In some illustrative examples, second sheet **402** is formed of Nomex. In some illustrative examples, second sheet **402** is formed of titanium. In some illustrative examples, first sheet **400** takes the form of an aluminum sheet and second sheet **402** takes the form of a titanium sheet.
[0068] Turning now to FIG. **5**, an illustration of an exploded view and an isometric view of a structural panel formed of a combined material honeycomb core is depicted in accordance with an illustrative embodiment. Structural panel **500** is a physical implementation of structural panel **223** of FIG. **2**. Structural panel **500** is formed by adhering facesheet **504** and facesheet **508** to combined material honeycomb core **502**. Combined material honeycomb core **502** can be the same as either combined material honeycomb core **312** of FIG. **3** formed through corrugation or combined material honeycomb core **408** of FIG. **4** formed through expansion. Adhesive **506** joins facesheet **504** to combined material honeycomb core **502**. Adhesive **510** joins facesheet **508** to combined material honeycomb core **502**. In some illustrative examples, facesheet **504** and facesheet **508** are formed of a composite. In some illustrative examples, facesheet **504** and facesheet **508** are formed of a metal.
[0069] In some illustrative examples, adhesive **506** and adhesive **510** are structural epoxy adhesives. Adhesive **506** and adhesive **510** are selected to provide desired material properties during operating and service temperatures for a platform, such as an aircraft. Adhesive **506** and adhesive **510** are also selected to be non-reactive with both the non-metallic material and the first metallic material of combined material honeycomb core **502**. Material considerations for adhesive **506** and adhesive **510** include temperature exposure, acoustical absorption, moisture/humidity, heat transfer and outgassing. Additional material considerations for adhesive **506** and adhesive **510** include corrosion/wear protection as well as mechanical properties including shear, tensile, compression, creep, impact, fatigue and peel.
[0070] Turning now to FIG. **6**, a flowchart of a method of manufacturing a combined material honeycomb core is depicted in accordance with an illustrative embodiment. Method **600** can be used to manufacture combined material honeycomb core for a portion of aircraft **100** of FIG. **1**. Method **600** can be used to manufacture combined material honeycomb core **202** of FIG. **2**. Method **600** can be used to manufacture a combined material honeycomb core according to expansion **236**. Method **600** can be used to manufacture combined material honeycomb core **408** of FIG. **4**. Method **600** can be used to manufacture combined material honeycomb core **502** of FIG. **5**.
[0071] Method **600** prints adhesive lines onto a sheet of a first material and a sheet of a second material (operation **602**). Method **600** cuts the sheet of the first material and the sheet of the second material into portions (operation **604**). Method **600** stacks the portions to form a stack comprising the first material and the second material (operation **606**). Method **600** cures the adhesive in the stack to form an adhered stack (operation **608**). Method **600** expands the adhered stack to form the combined material honeycomb core (operation **610**). Afterwards, method **600** terminates.
[0072] In some illustrative examples, method **600** determines a desired value of a material characteristic (operation **612**). In some illustrative examples, the material characteristic can include at least one of weight, strength to weight ratio, volume density, compressive strength, shear strength, heat transfer, electrical shielding, insulation, fatigue strength, or any other desirable characteristic. In some illustrative examples, the material characteristic can include at least one of corrosion/wear protection. In some illustrative examples, the material characteristic can include a mechanical property. In some illustrative examples, the material characteristic can include at least one of shear, tensile, compression, creep, impact, or fatigue and peel. In some illustrative examples, method **600** sets a ratio of the first material and the second material within the stack based on the desired value of the material characteristic (operation **614**).
[0073] In some illustrative examples, the first material is a first metallic material, and method **600**

further comprises applying a surface treatment to the sheet of the first material to increase adhesivity of the first material (operation **616**). In some illustrative examples, the surface treatment includes at least one of a mechanical treatment or a chemical treatment.

[0074] In some illustrative examples, stacking the portions to form the stack comprises alternating portions of the first material and the second material such that each cell of the combined material honeycomb core comprises both the first material and the second material (operation **618**).

[0075] In some illustrative examples, method **600** adheres a first facesheet to a first face of the combined material honeycomb core (operation **620**). In some illustrative examples, method **600** adheres a second facesheet to a second face of the combined material honeycomb core (operation **622**).

[0076] In some illustrative examples, adhering the second facesheet to the second face comprises adhering a composite sheet to the second face (operation **624**). In some illustrative examples, adhering the first facesheet to the first face comprises adhering a metal sheet to the first face (operation **626**).

[0077] In some illustrative examples, adhering the first facesheet to the first face comprises applying a same adhesive material (operation **628**).

[0078] Turning now to FIG. **7**, a flowchart of a method of manufacturing a combined material honeycomb core is depicted in accordance with an illustrative embodiment. Method **700** can be used to manufacture combined material honeycomb core for a portion of aircraft **100** of FIG. **1**. Method **700** can be used to manufacture combined material honeycomb core **202** of FIG. **2**. Method **700** can be used to manufacture a combined material honeycomb core using corrugation **238** of FIG. **2**. Method **700** can be used to manufacture combined material honeycomb core **312** of FIG. **3**. Method **700** can be used to manufacture combined material honeycomb core **502** of FIG. **5**.

[0079] Method **700** corrugates a plurality of sheets of a first material to form a first plurality of sheets of corrugated material (operation **702**). Method **700** corrugates a plurality of sheets of a second material to form a second plurality of sheets of corrugated material (operation **704**). Method **700** adheres the first plurality of sheets of corrugated material and the second plurality of sheets of corrugated material to form a honeycomb having an array of cells (operation **706**). Method **700** cures the adhesive joining the array of cells of the honeycomb to form the combined material honeycomb core (operation **708**). Afterwards, method **700** terminates.

[0080] In some illustrative examples, method **700** determines a desired value of a material characteristic (operation **712**). In some illustrative examples, the material characteristic can include at least one of weight, strength to weight ratio, volume density, compressive strength, shear strength, heat transfer, electrical shielding, insulation, fatigue strength, or any other desirable characteristic. In some illustrative examples, the material characteristic can include at least one of corrosion/wear protection. In some illustrative examples, the material characteristic can include a mechanical property. In some illustrative examples, the material characteristic can include at least one of shear, tensile, compression, creep, impact, or fatigue and peel. In some illustrative examples, method **700** sets a ratio of the first material and the second material within the honeycomb based on the desired value of the material characteristic (operation **714**).

[0081] In some illustrative examples, the first material is a first metallic material, and method **700** applies a surface treatment to the first material to increase adhesivity of the first material prior to adhering the first plurality of sheets of corrugated material and the second plurality of sheets of corrugated material (operation **716**). In some illustrative examples, the surface treatment includes at least one of a mechanical treatment or a chemical treatment.

[0082] In some illustrative examples, method **700** adheres the first plurality of sheets of corrugated material and the second plurality of sheets of corrugated material to form a honeycomb comprises alternating the first material and the second material such that each cell of the combined material honeycomb core comprises both the first material and the second material (operation **718**). By alternating the first plurality of sheets of corrugated material and the second plurality of sheets of

corrugated material, half of each cell is formed of first material and half of each cell is formed of second material.
[0083] In some illustrative examples, method **700** adheres a first facesheet to a first face of the combined material honeycomb core (operation **720**). In some illustrative examples, method **700** adheres a second facesheet to a second face of the combined material honeycomb core (operation **722**). In some illustrative examples, adhering the second facesheet to the second face comprises adhering a composite sheet to the second face (operation **724**). In some illustrative examples, adhering the first facesheet to the first face comprises adhering a metal sheet to the first face (operation **726**). In some illustrative examples, adhering the first facesheet to the first face comprises applying a same adhesive material (operation **728**).
[0084] Turning now to FIG. **8**, a flowchart of a method of manufacturing a combined material honeycomb core is depicted in accordance with an illustrative embodiment. Method **800** can be used to manufacture combined material honeycomb core for a portion of aircraft **100** of FIG. **1**. Method **800** can be used to manufacture combined material honeycomb core **202** of FIG. **2**. Method **800** can be used to manufacture combined material honeycomb core **502** of FIG. **5**.
[0085] Method **800** three-dimensionally prints two materials to form a honeycomb having an array of cells, each cell of the array of cells comprising the two materials (operation **802**). Afterwards, method **800** terminates.
[0086] In some illustrative examples, the two materials comprise a first metallic material and one of a second metallic material or a non-metallic material. In some illustrative examples, the first metallic material comprises aluminum and the second metallic material comprises titanium. In some illustrative examples, the non-metallic material comprises a composite material. In some illustrative examples, the first metallic material comprises aluminum and the non-metallic material comprises a composite material. In some illustrative examples, the non-metallic material comprises Nomex.
[0087] In some illustrative examples, method **800** three-dimensionally prints a first facesheet (operation **803**). The first facesheet comprises any desirable material that can be three-dimensionally printed. In some illustrative examples, the first facesheet is a composite material. In some illustrative examples, the first facesheet is a metallic material.
[0088] In some illustrative examples, three-dimensionally printing the two materials to form a honeycomb comprises three-dimensionally printing the two materials on top of the first facesheet (operation **805**). In some illustrative examples, after three-dimensionally printing the first facesheet, the two materials are three-dimensionally printed onto the first facesheet.
[0089] In some illustrative examples, three- dimensionally printing the two materials to form the honeycomb forms a combined material honeycomb core, and method **800** adheres a first facesheet to a first face of the combined material honeycomb core (operation **804**). In some illustrative examples, three-dimensionally printing the two materials to form the honeycomb forms a combined material honeycomb core, and method **800** adheres a second facesheet to a second face of the combined material honeycomb core (operation **806**). In some illustrative examples, the first facesheet and the second facesheet are formed of the same material. In some illustrative examples, the first facesheet and the second facesheet are formed of different types of materials. In some illustrative examples, at least one of the first facesheet or the second facesheet is formed of a metallic material. In some illustrative examples, at least one of the first facesheet or the second facesheet is formed of a composite material.
[0090] In some illustrative examples, adhering the second facesheet to the second face comprises adhering a composite sheet to the second face (operation **808**). In some illustrative examples, adhering the first facesheet to the first face comprises adhering a metal sheet to the first face (operation **810**). In some illustrative examples, adhering the first facesheet to the first face comprises applying a same adhesive material (operation **812**).
[0091] In some illustrative examples, method **800** determines a desired value of a material

characteristic (operation **814**). In some illustrative examples, the material characteristic can include at least one of weight, strength to weight ratio, volume density, compressive strength, shear strength, heat transfer, electrical shielding, insulation, fatigue strength, or any other desirable characteristic. In some illustrative examples, the material characteristic can include at least one of corrosion/wear protection. In some illustrative examples, the material characteristic can include a mechanical property. In some illustrative examples, the material characteristic can include at least one of shear, tensile, compression, creep, impact, or fatigue and peel. In some illustrative examples, method **800** sets a ratio of the two materials within the honeycomb based on the desired value of the material characteristic (operation **816**).

[0092] In some illustrative examples, three-dimensionally printing the two materials to form the honeycomb comprises applying adhesive between the two materials (operation **818**). In some illustrative examples, method **800** cures the adhesive joining the two materials of the honeycomb to form a combined material honeycomb core (operation **820**).

[0093] In some illustrative examples, three-dimensional printing of two different materials is performed together. In some illustrative examples, three-dimensional printing of Nomex and a metallic material is performed together. In some illustrative examples, three-dimensional printing of two different metallic materials is performed together. In some illustrative examples, three-dimensional printing of the honeycomb core is performed as part of a specification or requirement. In some illustrative examples, three-dimensional printing of the honeycomb core is performed for a small and/or complicated final shape of the sandwich structure.

[0094] As used herein, the phrase “at least one of,” when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, or item C” may include, without limitation, item A, item A and item B, or item B. This example also may include item A, item B, and item C or item B and item C. Of course, any combinations of these items may be present. In other examples, “at least one of” may be, for example, without limitation, two of item A; one of item B; and ten of item C; four of item B and seven of item C; or other suitable combinations. The item may be a particular object, thing, or a category. In other words, at least one of means any combination items and number of items may be used from the list but not all of the items in the list are required.

[0095] As used herein, “a number of,” when used with reference to items means one or more items.

[0096] The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent at least one of a module, a segment, a function, or a portion of an operation or step.

[0097] In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram. Some blocks may be optional. For example, operation **612** through operation **628** may be optional. For example, operation **712** through operation **728** may be optional. As another example, operation **803** through operation **820** may be optional.

[0098] Illustrative embodiments of the present disclosure may be described in the context of aircraft manufacturing and service method **900** as shown in FIG. **9** and aircraft **1000** as shown in FIG. **10**. Turning first to FIG. **9**, an illustration of an aircraft manufacturing and service method in the form of a block diagram is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **900** may include specification and design **902** of aircraft **1000** in FIG. **10** and material procurement **904**.

[0099] During production, component and subassembly manufacturing **906** and system integration **908** of aircraft **1000** takes place. Thereafter, aircraft **1000** may go through certification and delivery **910** in order to be placed in service **912**. While in service **912** by a customer, aircraft **1000** is scheduled for routine maintenance and service **914**, which may include modification, reconfiguration, refurbishment, or other maintenance and service.

[0100] Each of the processes of aircraft manufacturing and service method **900** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

[0101] With reference now to FIG. **10**, an illustration of an aircraft in the form of a block diagram is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **1000** is produced by aircraft manufacturing and service method **900** of FIG. **9** and may include airframe **1002** with plurality of systems **1004** and interior **1006**. Examples of systems **1004** include one or more of propulsion system **1008**, electrical system **1010**, hydraulic system **1012**, and environmental system **1014**. Any number of other systems may be included.

[0102] Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **900**. One or more illustrative embodiments may be manufactured or used during at least one of component and subassembly manufacturing **906**, system integration **908**, in service **912**, or maintenance and service **914** of FIG. **9**.

[0103] The illustrative examples present combined material honeycomb cores and methods of manufacture. The illustrative examples recognize and take into account that Nomex is lower in weight than aluminum and other types of metal. Nomex has desirable levels of compression and shear and corrosion resistance.

[0104] Nomex core has less desirable temperature capability than aluminum and less comprehensive strength than aluminum.

[0105] The illustrative examples recognize and take into account that aluminum and other metals provide greater strength than Nomex and other non-metallic materials. However, aluminum produces a honeycomb core that is higher cost and has a higher density.

[0106] A combined material honeycomb core provides improved properties to the aircraft structures. combined material honeycomb core provides the ability to tailor the mechanical properties through the choice of materials and ratios of materials in the combined material honeycomb core. A combined material honeycomb core can provide increased strength to weight ratio, less maintenance, and improved revenue.

[0107] A combined material honeycomb core with aluminum and Nomex is a lightweight, recyclable material. A combination of aluminum and Nomex that offers an increased stiffness with one of the highest strength to weight ratios of any structural core material available.

[0108] A combination of metallic and Nomex honeycomb can provide improved properties to a composite structure. A combined material honeycomb core provides material advantages of both metallic & Nomex honeycombs. Composite material in a combined material honeycomb core provides a tension benefit while aluminum or other metallic material can provide improved compression. The combination material honeycomb core can reduce the amount of moisture absorbed within the core in comparison to a fully non-metallic core. Facesheets for a structural panel comprising combined material honeycomb core can take the form of either composite or metal face sheets. In some illustrative examples, an aluminum facesheet can have a film between it and the combined material honeycomb core to avoid undesirable galvanic behaviors. An exterior aluminum face sheet can reduce water ingress.

[0109] The description of the different illustrative embodiments has been presented for purposes of

illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A combined material honeycomb core that comprises: a first face; a second face; a plurality of cells that comprise multiple materials and are regularly arranged in an array, wherein the multiple materials comprise a first metallic material and either a meta-aramid material or a second metallic material different from the first metallic material formed as sheets stacked alternately in layers.
2. The combined material honeycomb core of claim 1, wherein each cell of the plurality of cells comprises the first metallic material and either the second metallic material or the meta-aramid material.
3. The combined material honeycomb core of claim 1, wherein the first metallic material comprises aluminum, and wherein the second metallic material comprises titanium.
4. The combined material honeycomb core of claim 1, wherein the first metallic material comprises aluminum.
5. The combined material honeycomb core of claim 1 further comprising a cured adhesive joining the plurality of cells.
6. The combined material honeycomb core of claim 1, wherein the combined material honeycomb core is recyclable, and further comprising a surface treatment to a sheet of the first metallic material to increase adhesivity of the first metallic material.
7. The combined material honeycomb core of claim 1, wherein the meta-aramid material is Nomex.
8. The combined material honeycomb core of claim 1, wherein the combined material honeycomb core is expanded.
9. The combined material honeycomb core of claim 1, wherein a material characteristic of the combined material honeycomb core is based upon a ratio a ratio of the first metallic material and the meta-aramid material.
10. The combined material honeycomb core of claim 1, wherein at least one of: a weight, a strength to weight ratio, a volume density, a compressive strength, a shear strength, a heat transfer, an electrical shielding, an insulation, or a fatigue strength, of the combined material honeycomb core is based upon a ratio of the metallic material and the meta-aramid material.
11. The combined material honeycomb core of claim 1, further comprising: a first facesheet adhered to a first face of the combined material honeycomb core; and a second facesheet adhered to a second face of the combined material honeycomb core.
12. A structural panel that comprises a combined material honeycomb core that comprises: a first face; a second face; a plurality of cells formed of multiple materials, wherein the multiple materials comprise a first metallic material and either a meta-aramid material or a second metallic material different from the first metallic material; a first facesheet adhered to the first face of the combined material honeycomb core; and a second facesheet adhered to the second face of the combined material honeycomb core.
13. The structural panel of claim 12, wherein the first facesheet and the second facesheet are formed of different materials.
14. The structural panel of claim 13, wherein the first facesheet comprises a metallic material and the second facesheet comprises a meta-aramid material.
15. The structural panel of claim 13, further comprising: a first layer of structural adhesive between

the first facesheet and the first face of the combined material honeycomb core; and a second layer of structural adhesive between the second facesheet and the second face of the combined material honeycomb core, the first layer of structural adhesive and the second layer of structural adhesive formed of a same adhesive material.

16. The structural panel of claim 12, wherein a ratio of the first metallic material and the meta-aramid material determines a value of at least one of: a weight, a strength to weight ratio, a volume density, a compressive strength, a shear strength, a heat transfer, an electrical shielding, an insulation, or a fatigue strength, of the combined material honeycomb core.

17. The structural panel of claim 12, wherein the combined material honeycomb core is expanded.

18. The structural panel of claim 12, wherein the combined material honeycomb core comprise corrugated layers of the multiple materials.

19. The structural panel of claim 12, wherein the multiple materials comprise three dimensionally printed layers.

20. A structural panel that comprises a combined material honeycomb core that comprises: a first face; a second face; a plurality of cells formed of multiple materials, wherein the multiple materials form alternating layers of a metallic material and a meta-aramid material, wherein a ratio of the metallic material and the meta-aramid material determines a value of at least one of: a weight, a strength to weight ratio, a volume density, a compressive strength, a shear strength, a heat transfer, an electrical shielding, an insulation, or a fatigue strength, of the combined material honeycomb core; a first facesheet adhered to the first face of the combined material honeycomb core; a first layer of structural adhesive between the first facesheet and the first face of the combined material honeycomb core; a second facesheet adhered to the second face of the combined material honeycomb core; and a second layer of structural adhesive between the second facesheet and the second face of the combined material honeycomb core.