United States Patent	12384515
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Kilchyk; Viktor et al.

Airfoil formed of thermally adaptive materials and a thermoelectric junction

Abstract

An airfoil having: a composition gradient defining a first coefficient of thermal expansion and a second coefficient of thermal expansion that differs from the first coefficient of thermal expansion; and a thermoelectric junction operationally coupled to the composition gradient, wherein the composition gradient is formed of either of a plurality of dissimilar metals or of plastic with fillings or fibers.

Inventors: **Kilchyk; Viktor (Lancaster, NY), Merritt; Brent J. (Southwick, MA)**

Applicant: **Hamilton Sundstrand Corporation** (Charlotte, NC)

Family ID: **1000008747615**

Assignee: **HAMILTON SUNDSTRAND CORPORATION (Charlotte, NC)**

Appl. No.: **18/464159**

Filed: **September 08, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20250083795 A1	Mar. 13, 2025

Publication Classification

Int. Cl.: **B64C3/48** (20060101); **B64C3/14** (20060101); **H10N10/17** (20230101)

U.S. Cl.:

CPC **B64C3/48** (20130101); **B64C3/14** (20130101); **H10N10/17** (20230201);

Field of Classification Search

CPC: B64C (3/48); B64C (2003/445); H10N (10/17)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
3326726	12/1966	Bassett, Jr.	136/203	H10N 10/17
4327154	12/1981	Rossmann	N/A	N/A
4851285	12/1988	Brotz	976/DIG.413	G21H 1/06
4939038	12/1989	Inabata	N/A	N/A
5230850	12/1992	Lewis	N/A	N/A
5634189	12/1996	Rossmann	428/548	F01D 5/28
6100463	12/1999	Ladd et al.	N/A	N/A
6161382	12/1999	Brotz	N/A	N/A
6182929	12/2000	Martin et al.	N/A	N/A
7037076	12/2005	Jacot et al.	N/A	N/A
7147269	12/2005	Aase et al.	N/A	N/A
7650910	12/2009	Welle	N/A	N/A
7686040	12/2009	Welle	N/A	N/A
7721762	12/2009	Welle	N/A	N/A
7753654	12/2009	Read	416/500	F02C 7/045
7770959	12/2009	Browne et al.	N/A	N/A
7854467	12/2009	Mcknight et al.	N/A	N/A
7922456	12/2010	McMillan	416/232	F01D 5/147
7967568	12/2010	Dalton et al.	N/A	N/A
8119206	12/2011	Hougham et al.	N/A	N/A
9181933	12/2014	Daly et al.	N/A	N/A
9719536	12/2016	Ashmawi	N/A	F16B 2/08
9752442	12/2016	Hayford et al.	N/A	N/A
9784126	12/2016	Army et al.	N/A	N/A
9897078	12/2017	Nicholson et al.	N/A	N/A
9919470	12/2017	Behl et al.	N/A	N/A
9981421	12/2017	Marcoe et al.	N/A	N/A
10053239	12/2017	Mabe	N/A	B32B 3/28
10543897	12/2019	Brown	N/A	B64C 3/185
10731666	12/2019	Skertic	N/A	N/A
10815976	12/2019	Kaneko et al.	N/A	N/A
10976119	12/2020	Veto et al.	N/A	N/A
10982783	12/2020	Srinivasa Murthy	N/A	N/A
11008943	12/2020	Tajiri et al.	N/A	N/A
11110647	12/2020	Marcoe et al.	N/A	N/A
11167836	12/2020	Hethcock, Jr.	N/A	N/A
11192333	12/2020	Hahnlen	N/A	N/A
11248592	12/2021	Tsuruta et al.	N/A	N/A
11268520	12/2021	Melo et al.	N/A	N/A

11359287	12/2021	Philibert	N/A	N/A
11655346	12/2022	Jackson et al.	N/A	N/A
11668316	12/2022	Kilchyk	416/185	B22F 10/28
12162606	12/2023	Merritt	N/A	B33Y 80/00
2001/0008357	12/2000	Dhuler et al.	N/A	N/A
2007/0140862	12/2006	Mcmillan	N/A	N/A
2007/0171257	12/2006	Yang	N/A	N/A
2007/0184238	12/2006	Hockaday et al.	N/A	N/A
2008/0236668	12/2007	Beerling et al.	N/A	N/A
2008/0302024	12/2007	Browne et al.	N/A	N/A
2010/0028205	12/2009	Ponjee et al.	N/A	N/A
2010/0304063	12/2009	McCrea et al.	N/A	N/A
2011/0284645	12/2010	Tiliakos et al.	N/A	N/A
2012/0255278	12/2011	Miao et al.	N/A	N/A
2013/0048135	12/2012	Blumenthal et al.	N/A	N/A
2013/0255796	12/2012	Dimascio et al.	N/A	N/A
2013/0255815	12/2012	Brinkmann et al.	N/A	N/A
2013/0287555	12/2012	Rosen	415/182.1	F04D 29/0513
2014/0186161	12/2013	Colson et al.	N/A	N/A
2015/0033730	12/2014	Beers et al.	N/A	N/A
2015/0239046	12/2014	McMahan et al.	N/A	N/A
2016/0025078	12/2015	Li et al.	N/A	N/A
2016/0160353	12/2015	Miarecki et al.	N/A	N/A
2016/0186575	12/2015	Lacy et al.	N/A	N/A
2017/0001263	12/2016	Steiner	N/A	N/A
2017/0227019	12/2016	Chen et al.	N/A	N/A
2018/0038513	12/2017	Baldea et al.	N/A	N/A
2018/0043660	12/2017	Kang et al.	N/A	N/A
2018/0058429	12/2017	Kwon	N/A	H10N 19/101
2019/0203039	12/2018	Seo et al.	N/A	N/A
2019/0210111	12/2018	Army et al.	244/1	B22F 5/009
2020/0009826	12/2019	Brown et al.	N/A	N/A
2020/0316684	12/2019	Shuck	N/A	N/A
2021/0020263	12/2020	Pasini et al.	N/A	N/A
2021/0071020	12/2020	Hu	N/A	N/A
2021/0085856	12/2020	Ding	N/A	N/A
2021/0229350	12/2020	Chaffins et al.	N/A	N/A
2021/0238748	12/2020	Andreatta	N/A	N/A
2021/0277937	12/2020	Elbibary et al.	N/A	N/A
2021/0372286	12/2020	Chakrabarti et al.	N/A	N/A
2022/0034592	12/2021	Maynard et al.	N/A	N/A
2022/0089799	12/2021	Wang et al.	N/A	N/A
2023/0080512	12/2022	Merritt et al.	N/A	N/A
2023/0085189	12/2022	Merritt et al.	N/A	N/A
2023/0142146	12/2022	Kilchyk	N/A	N/A

2023/0227680	12/2022	Hu	N/A	N/A
2025/0033270	12/2024	Merritt et al.	N/A	N/A
2025/0033271	12/2024	Merritt et al.	N/A	N/A
2025/0033272	12/2024	Merritt et al.	N/A	N/A
2025/0033282	12/2024	Merritt et al.	N/A	N/A
2025/0033283	12/2024	Merritt et al.	N/A	N/A
2025/0033796	12/2024	Merritt et al.	N/A	N/A
2025/0084766	12/2024	Kilchyk et al.	N/A	N/A
2025/0084833	12/2024	Kilchyk et al.	N/A	N/A
2025/0084834	12/2024	Kilchyk et al.	N/A	N/A
2025/0084859	12/2024	Kilchyk et al.	N/A	N/A
2025/0085725	12/2024	Kilchyk et al.	N/A	N/A
2025/0088125	12/2024	Kilchyk et al.	N/A	N/A
2025/0089567	12/2024	Kilchyk et al.	N/A	N/A
2025/0089568	12/2024	Kilchyk et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
10250758	12/2003	DE	N/A
102014225229	12/2015	DE	N/A
2025777	12/2008	EP	N/A
2974954	12/2015	EP	N/A
2960497	12/2015	EP	N/A
4177440	12/2022	EP	N/A
4209681	12/2022	EP	N/A
4219959	12/2022	EP	N/A
4411108	12/2023	EP	N/A
2472053	12/2010	GB	N/A
2007023361	12/2006	JP	N/A
2011148037	12/2010	JP	N/A
20130005989	12/2012	KR	N/A
2015006438	12/2014	WO	N/A
WO-2018108908	12/2017	WO	H01F 7/1638
2019108203	12/2018	WO	N/A
2019162754	12/2018	WO	N/A

OTHER PUBLICATIONS

Niccolo Giani, Towards sustainability in 3D printing of thermoplastic composites: Evaluation of recycled carbon fibers as reinforcing agent for FDM filament production and 3D printing, May 19, 2022, elsavier compoites part A 159 (2022) 107002 (Year: 2022). cited by examiner
Loredana Tammaro, Reinforcing Efficiency of Recycled Carbon Fiber PLA Filament Suitable for Additive Manufacturing, Jul. 23, 2024, Polymers 2024, 16, 2100 (Year: 2024). cited by examiner
Kim, Daejong, “Parametric Studies on Static and Dynamic Performance of Air Foil Bearings with Different Top Foil Geometries and Bump Stiffness Distributions”, https://doi.org/10.1115/1.2540065; Published Online: Nov. 15, 2006, 9 pages. cited by applicant
Lim, Teik-Cheng “Metamaterial with sign-toggling thermal expansivity inspired by Islamic motifs in Spain”, Journal of Science: Advanced Materials and Devices, vol. 7, No. 1, Mar. 2022, 6 pages. cited by applicant
Micalizz, et al., “Shape-memory actuators manufacturing by dual extrusion multimaterial 3d

printing of conductive and non-conductive filaments", Smart Mater. Struct. 28, 2019, pp. 1-13. cited by applicant
Schmiedeke, et al. "Experimental Investigation of Two Switching States of an Active Foil Bearing during Start-Up", Machines 2022, Published Jun. 6, 2022, 18 pages. cited by applicant
Wei, et al., "An overview of laser-based multiple metallic material additive manufacturing: from macro-to micro-scales", International Journal of Extrem. Manuf. 3 (2021), pp. 1-33. cited by applicant
Markforged "Onyx FR-A and Carbon Fiber FR-A: Aerospace-Ready Materials", markforged.com, Jul. 26, 2021, pp. 1-6. cited by applicant
Noughabi et al., "Detailed Design and Aerodynamic Performance Analysis of a Radial-Inflow Turbine", Applied Sciences, 2018, pp. 1-21. cited by applicant
Pearson et al., "Novel polyurethane elastomeric composites reinforced with alumina, aramid, and poly (p-phenylene-2, 6-benzobisoxazole) short fibers, development and characterization of the thermal and dynamic mechanical properties", Composites Part B: Engineering 122 (2017): 192-201. cited by applicant
Zhan et al., "Metal-plastic hybrid 3D printing using catalyst-loaded filament and electroless plating", Additive Manufacturing, 2020, pp. 1-7. cited by applicant
Zhiguo et al., "Determination of thermal expansion coefficients for unidirectional fiber-reinforced composites", Chinese Journal of Aeronautics, 2014, pp. 1-14. cited by applicant
European Search Report for Application No. 224188681.1, mailed Dec. 4, 2024, 10 pages. cited by applicant
European Search Report for Application No. 24196227.3, mailed Oct. 31, 2024, 10 pages. cited by applicant
European Search Report for Application No. 24196233.1, mailed Oct. 31, 2024, 10 pages. cited by applicant
European Search Report for Application No. 24198989.6, mailed Nov. 4, 2024, 11 pages. cited by applicant
Doering et al., "Micromachined thermoelectrically driven cantilever structures for fluid jet deflection" [1992] Proceedings IEEE Micro Electro Mechanical Systems. IEEE, (Feb. 1992) pp. 12-18. cited by applicant
European Search Report for Application No. 24196295.0, mailed Jan. 29, 2025, 16 pages. cited by applicant
European Search Report for Application No. 24196309.9, mailed Jan. 28, 2025, 10 pages. cited by applicant
Jerman "Electrically-activated, micromachined diaphragm valves" IEEE 4th Technical Digest on Solid-State Sensor and Actuator Workshop, Hilton Head, SC, USA, (Jun. 1990) pp. 65-69. cited by applicant
Jerman et al., "Electrically activated normally closed diaphragm valves" Journal of Micromechanics and Microengineering 4.4 (Dec. 1994) pp. 210-216. cited by applicant
European Search Report for Application No. 24188696.9, mailed Dec. 16, 2024, 8 pages. cited by applicant
European Search Report for Application No. 24188713.2, mailed Jan. 2, 2025, 6 pages. cited by applicant
European Search Report for Application No. 24188714.0, mailed Dec. 13, 2024, 10 pages. cited by applicant
European Search Report for Application No. 24190738.5, mailed Jan. 13, 2025, 8 pages. cited by applicant
European Search Report for Application No. 24196219.0, mailed Jan. 13, 2025, 8 pages. cited by applicant
European Search Report for Application No. 24199038.1, mailed Jan. 31, 2025, 8 pages. cited by

applicant
Partial European Search Report for Application No. 24196240.6, mailed Feb. 7, 2025, 16 pages. cited by applicant
Richardson,, “The aerospace secret standard”, Apr. 12, 2019, Aerospace Manufacturing, www.aero-mag.com/the-aerospace-secret-standard; 8 pages. cited by applicant
Extended European Search Report for EP Application No. 24182403.6, dated Jun. 2, 2025, pp. 1-11. cited by applicant
Extended European Search Report for EP Application No. 24196240.6, dated Apr. 28, 2025, pp. 1-13. cited by applicant
Lazarus et al., “Direct electroless plating of conductive thermoplastics for selective metallization of 3D printed parts”, Additive Manufacturing, vol. 55, Mar. 30, 2022, pp. 1-11. cited by applicant

---

Primary Examiner: O'Hara; Brian M

Attorney, Agent or Firm: CANTOR COLBURN LLP

Background/Summary

BACKGROUND
(1) The embodiments are directed to an airfoil and more specifically to an airfoil formed of thermally adaptive materials and a thermoelectric junction.
(2) Memory shape alloy or bimetallic parts may be utilized for various applications to avoid the requirement of utilizing complex machinery. However, working fluid temperatures may undesirably control the shape of the alloy.
BRIEF DESCRIPTION
(3) Disclosed is an airfoil including: a composition gradient defining a first coefficient of thermal expansion and a second coefficient of thermal expansion that differs from the first coefficient of thermal expansion; and a thermoelectric junction operationally coupled to the composition gradient, wherein the composition gradient is formed of either of a plurality of dissimilar metals or of plastic with fillings or fibers.
(4) In addition to one more aspects of the airfoil, or as an alternate, the airfoil includes a base formed by the composition gradient defining the first coefficient of thermal expansion and the second coefficient of thermal expansion that differs from the first coefficient of thermal expansion, so that: the base defines an outer boundary and beads within the outer boundary, each of the beads has a bead void, and each of the beads includes: first and second perimeter segments that are opposite each other and formed to define the first CTE; and third and fourth perimeter segments that are opposite each other, adjacent to the first and second perimeter segments, and formed to define the second CTE; and the thermoelectric junction is provided around the outer boundary or in one or more of the bead voids.
(5) In addition to one more aspects of the airfoil, or as an alternate, each perimeter segment has a radial inner portion and a radial outer portion; the radial inner portion of the first and second perimeter segments is formed of to define the first CTE and the radial outer portion of the first and second perimeter segments is formed to define the second CTE; and the radial inner portion of the third and fourth perimeter segments is formed to define the second CTE and the radial outer portion of the third and fourth perimeter segments is formed to define of the first CTE.
(6) In addition to one more aspects of the airfoil, or as an alternate, adjacent ones of the beads are interconnected to form a lattice.
(7) In addition to one more aspects of the airfoil, or as an alternate, the outer boundary defines a

first outer end and a second outer end, wherein the first and second outer ends are opposite each other, and the base includes a top elastomer layer that is disposed against the first outer end of the outer boundary and a bottom elastomer layer that is disposed against the second outer end of the outer boundary.
(8) In addition to one more aspects of the airfoil, or as an alternate, the base includes an elastomer segment that extends from each of the beads that are located along the outer boundary of the base, so that adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.
(9) In addition to one more aspects of the airfoil, or as an alternate, the base includes a support material that forms a support structure that defines the outer boundary of the base and a plurality of base voids, wherein each of the plurality of base voids is lined with one of the beads.
(10) In addition to one more aspects of the airfoil, or as an alternate, the support material differs from the bead.
(11) In addition to one more aspects of the airfoil, or as an alternate, the beads define an oval or diamond shape.
(12) In addition to one more aspects of the airfoil, or as an alternate, the thermoelectric junction is a Peltier airfoil.
(13) In addition to one more aspects of the airfoil, or as an alternate, the composition gradient is formed of a first material having the first CTE and a second materials having the second CTE, and one or both of the first and second materials is a bistable metal, alloy or composite.
(14) In addition to one more aspects of the airfoil, or as an alternate, the airfoil includes a base defining a first CTE, and a second CTE that differs from the first CTE, wherein the base defines an outer boundary and extends in a first direction from first end to a second end and in a second direction from a first side to a second side, so that: a first layer extends in the first direction between the first and second ends to define the first CTE; a second layer extends in the first direction between the first and second ends to define the second CTE, wherein a layer junction is defined between the first and second layers; and a thermoelectric junction extends along the layer junction or the outer boundary.
(15) In addition to one more aspects of the airfoil, or as an alternate, the base includes a chain of connected elements.
(16) In addition to one more aspects of the airfoil, or as an alternate, the elements define an arcuate shape.
(17) In addition to one more aspects of the airfoil, or as an alternate, one or both of the first and second layers are formed of first and second materials, one or both of which is a bistable metal, alloy or composite.
(18) In addition to one more aspects of the airfoil, or as an alternate, the thermoelectric junction is a Peltier airfoil.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:
(2) FIG. **1**A shows an aircraft according to embodiment;
(3) FIG. **1**B shows an airfoil according to an embodiment, where the airfoil has a first camber profile;
(4) FIG. **1**C shows the same airfoil of FIG. **1**B with a second camber profile;
(5) FIG. **2** shows a section of the airfoil, having a base formed of a lattice of beads utilizing composition gradients across the hoop-shaped walls, having inner and outer surfaces, to define

perimeter segments along the walls of the beads, where the segments have different coefficients of thermal expansion (CTE) selected to provide a predetermined deformation, and where the lattice is formed with a thermoelectric junction;
(6) FIG. **3** shows the lattice of beads in a normal state;
(7) FIG. **4** shows the lattice of beads in a deformed state;
(8) FIG. **5** shows an embodiment of a bead utilized in the configuration shown in FIGS. **2-4**, where the bead is in a normal state;
(9) FIG. **6** shows the bead of FIG. **5** in a deformed state;
(10) FIG. **7** shows the lattice of beads of FIG. **2** with top and bottom elastomer layers;
(11) FIG. **8** shows a plurality of the beads, from the lattice of beads of FIG. **2**, with an elastomer segment extending from each bead, over an adjacent bead, to form a continuous elastomer boundary;
(12) FIG. **9** shows an alternate configuration of the section of the airfoil, having a base that defines voids, where ones of the voids are lined with the beads shown in FIGS. **2-4**, and a thermoelectric junction is formed either within at least one of the beads or around the base, and where the base is in a normal state;
(13) FIG. **10** shows the section of FIG. **9** in a deformed state;
(14) FIG. **11** shows another configuration of the section of the airfoil, having a base formed of a composition gradient defined by two material layers that extend alongside each other, where the two material layers have different CTEs selected to provide a predetermined deformation when subjected to heating, where a thermoelectric junction is formed between the two material layers, and where the section is in a normal state;
(15) FIG. **12** shows the section of FIG. **11** in a deformed state;
(16) FIG. **13** shows an alternate configuration relative to the configuration of FIG. **11**, where the composition gradient, formed of the two material layers, are formed of semicircular elements connected to one another, and where the section is in a normal state;
(17) FIG. **14** shows the section of FIG. **13** in a deformed state;
(18) FIG. **15** shows an oval shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. **2-10**, in a normal state;
(19) FIG. **16** shows the bead of FIG. **15** in a deformed state;
(20) FIG. **17** shows a diamond shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. **2-10**, in a normal state;
(21) FIG. **18** shows the bead of FIG. **17** in a deformed state;
(22) FIG. **19** shows a random shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. **2-10**, in a normal state;
(23) FIG. **20** shows the bead of FIG. **17** in a deformed state;
(24) FIG. **21** shows an equivalent structure with a composition gradient formed of a plurality of materials having different coefficients of thermal expansion (CTE), at a temperature T**1**; and
(25) FIG. **22** shows the structure of FIG. **21** at a temperature T**2**>T**1**.
DETAILED DESCRIPTION
(26) A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.
(27) FIG. **1**A shows an aircraft **1** having a fuselage **2** with a wing **3** and tail assembly **4**, which may have control surfaces **5**. The wing **3** may include an engine **6**, such as a gas turbine engine, and an auxiliary power unit **7** may be disposed at the tail assembly **4**. FIG. **1**B shows an airfoil **10** of the aircraft **1** according to an embodiment. The airfoil **10** can be applied to fan blades, helicopter blades, rocket control surfaces, turbine blades, etc. The airfoil may have a leading edge **10**A, a trailing edge **10**B, a chord extending **10**C between the leading and trailing edges **10**A, **10**B, and the airfoil skin **10**D may define a first camber profile. FIG. **1**C shows the same airfoil with a second camber profile, which is increased relative to the first camber profile, by pitching an aft portion

10E of the airfoil relative to a forward portion **10**F. That is, a pitch region **10**G is located at an intersection between the forward and aft portions **10**F, **10**E.
(28) In one embodiment, as shown in FIG. **2**, the airfoil **10** may be additively manufactured with a base **70**, utilized at least for the pitch region **10**G of the airfoil of FIGS. **1**A-**1**B, formed to have a composition gradients across the hoop-shaped walls **50**, having an outer surface **52**, an inner surface **54**, to define first through fourth perimeter segments **110**, **120**, **130**, **140** along the walls of the beads. The segments **110**, **120**, **130**, **140** have different coefficients of thermal expansion (CTE) selected to provide a predetermined deformation. The lattice is formed with a thermoelectric junction. The composition gradient may be formed of a first material having a first coefficient of thermal expansion (CTE) and a second material having a second CTE that differs from the first CTE. The composition gradient may be formed by the utilization of different metals or may be formed by plastic, fillings or fibers. The base **70** may define an outer boundary **80** and a lattice of beads **90** within the boundary **80**. The beads **90** may have an oval cross section, though such shape is not intended on limiting the scope of the embodiments.
(29) Each of the beads **90** may have a bead void **100** or cavity and may include the first and second perimeter segments **110**, **120** that are opposite each other. The beads **90** may include the third and fourth perimeter segments **130**, **140** that are opposite each other, adjacent to the first and second perimeter segments **110**, **120**. With this configuration, each of the beads **90** forms a circumferential (or perimeter) CTE gradient.
(30) Adjacent ones of the beads **90** may be interconnected with each other, e.g., along the perimeter segments **110-140**. With this interconnected configuration, the beads **90** form the lattice.
(31) A thermoelectric junction **150** may be disposed in one more of the bead voids **100**, or may be disposed around the boundary **80** of the base **70**. The thermoelectric junction **150** may form a Peltier or a Thomson device. For example, alternating P and N-type pillars made with materials with different Seebeck coefficients, or legs, are placed thermally in parallel to each other and electrically in series and joined with a thermally conducting plate on each side, e.g., ceramic, including a cooling plate **160** and a heating plate **170**. When a voltage is applied to the free ends of the two semiconductors, via connections **190** there is a flow of DC current across the junction of the semiconductors, causing a temperature difference. The side with the cooling plate **160** absorbs heat which is then transported by the semiconductor to the other side of the device. One of the cooling plate **160** or heating plate **170** may be exposed to the atmosphere if desired to bleed energy from it rather than directing energy from it back to the airfoil **10**.
(32) The beads **90** may be formed of a bistable metal, alloy or composite. The beads **90** may be configured to change shape by a predetermined amount when subject to thermal input, e.g., heat, due to the second CTE obtained with the composition gradient. For example, when the beads **90** are subject to thermal input from the thermoelectric junction **150** (FIG. **2**), shape of the base **70** may change from a first state (FIG. **3**) to a second state (FIG. **4**). In the first state, the base **70** may extend in a first direction (or length direction) to define a first length L**1** and in a second direction (or width direction) to define a first width W**1**. In the second state the base **70** may extend in the first direction to define a second length L**2** and in the second direction to define a second width W**2**. From the shape change, one of the first length and width L**1**, W**1** may be greater or smaller than a corresponding one of the second length and width L**2**, W**2**. As shown in FIGS. **3** and **4**, the first width W**1** is greater than the second width W**2** and the first and second lengths L**1**, L**2** are the same as each other.
(33) As shown in FIGS. **5** and **6**, in one embodiment, each perimeter segment **110-140** may have a radial inner portion **200** (the above noted inner surface **54**) and a radial outer portion **210** (the above noted outer surface **52**). It is to be appreciated that the use of the term radial in this context does not require a circular cross section but rather references a distance from a center of the bead **90**. The inner portion **200** of the first and second perimeter segments **110**, **120** may be formed to have a first CTE and the outer portion **210** of the first and second perimeter segments **110**, **120** may

be formed to have a second CTE. As indicated, this may be obtained from different metals (e.g., first and second materials corresponding to first and second metals) or from plastic, fillings, or fibers. The inner portion **200** of the third and fourth perimeter segments **130**, **140** may be formed to have the second CTE and the outer portion **210** of the third and fourth perimeter segments **130**, **140** may be formed to have the first CTE. FIG. **5** shows the bead **90** in a first state when the thermoelectric junction **150** (FIG. **2**) is not providing thermal input and FIG. **6** shows the bead in a second state when thermoelectric junction **150** is providing thermal input. The embodiment shown in FIGS. **5** and **6** provides a radial CTE gradient that results in a tailored deformation of the beads **90** upon receiving thermal input from the thermoelectric junction **150**.

(34) As shown in FIG. **7**, the outer boundary **80** defines a first outer end **230** and a second outer end **240**. The first and second outer ends **230**, **240** are opposite each other. In one embodiment, a top elastomer layer **250** is disposed against the top end **230** of the outer boundary **80** and a bottom elastomer layer **260** is disposed against the bottom end **240** of the outer boundary **80**.

(35) As shown in FIG. **8**, in one embodiment, an elastomer segment **270** extends from each of the beads **90** disposed at the outer boundary **80** of the lattice of beads **90**. With this configuration, adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.

(36) Turning to FIGS. **9** and **10**, in one embodiment, the base **70** of the airfoil **10** may be manufactured with a support structure **280** that may define the outer boundary **80** of the base **70** and internal base voids **290** or cavities. Each of the base voids **290** may be lined with one of above disclosed beads **90** and thus have a cavity surface **300** defining a cross sectional shape that is complementary to the shape of the beads **90**. The support structure **280** may be formed of a support material that differs from the bead material. An exterior surface **85**, surrounding the outer boundary **80** of the base **70**, maybe be coated with the materials that form the bead **90**. The support material may be an elastomer, a metal, an alloy or a composite. A thermoelectric junction **150** may be provided around the outer boundary **80** or in one or more of the bead voids **100**.

(37) FIGS. **9** and **10** show the base **70** in the first state, having a first length and width L**1**, W**1**, and the second state, having a second length and width L**2**, W**2**. As indicated above, from the shape change, one of the first length and width L**1**, W**1** may be greater or smaller than a corresponding one of the second length and width L**2**, W**2**. In the illustrated embodiment, the second width W**2** is smaller than the first width W**1** and the first and second lengths L**1**, L**2** are the same as each other.

(38) FIGS. **11** and **12** show another embodiment in which the airfoil **10** may be additively manufactured to form a base **70** having a composition gradient. The composition gradient may define a first CTE, and a second CTE that differs from the first CTE. As indicated, this may be obtained from different metals (e.g., first and second materials corresponding to first and second metals) or from plastic, fillings, or fibers. The base **70** extends in a first direction (e.g., a length direction) from first end **310** to a second end **320** and in a second direction (e.g., a width direction) from a first side **330** to a second side **34**. The base **70** defines an outer boundary **80**. The first CTE may be formed from a first composition layer **350** that extends in the first direction between the first and second ends **310**, **320**, and in the second direction between the first side of the base **70** and a layer junction **370**. The second CTE may be formed in a second composition layer **360** that extends in the first direction between the first and second ends **310**, **320**, and in the second direction between the second side **340** and the composition junction **370**. That is, the first and second layers **350**, **360** extend alongside each other. With this configuration, a transverse CTE gradient is formed in the base **70**. A thermoelectric junction **150** may extend along the first direction at the layer junction **370**, between the first and second composition layers **350**, **360**, or along the boundary **80** of the base **70**.

(39) The first and second composition layers each may be a bistable metal, alloy or composite. The base **70** may extend in the first direction by a first length L**1** and in the second direction by a first width W**1**. Due to the different coefficients of thermal expansion, when subjected to thermal input

by the thermoelectric junction **150**, the base **70** may deform as shown in FIG. **11** to form an arcuate shape. When in the deformed state, a longer side of the base **70** may have a length L**2** that is greater than the first length L**1**, though projected along first direction the base **70** has a second length L**2**x that is shorter than the first length L**1**. The width may be unchanged.
(40) As shown in FIGS. **13** and **14**, between opposite ends **310**, **320**, in one embodiment the first and second layers form a chain of elements **380** connected at circumferential ends **390**, **400**. The elements **380** are illustrated as having a semicircular shape, though that is not intended on limiting the scope of the embodiments. FIG. **13** shows the base **70** is in a normal state, having a first length L**1**. FIG. **14** shows the base **70** in a deformed state, from thermal input from the thermoelectric junction **150**, having a second length L**2** which is smaller than the first length L**1**.
(41) FIG. **15** shows an oval shaped bead **90**, which may be formed as indicated above, in a normal state having a first width W**1**. FIG. **16** shows the oval bead **90** in a deformed state having a second width W**2** that is less than the first width W**1**. As indicated, the beads **90** do not need to be arcuate in shape. FIG. **17** shows a diamond shaped bead **90** in a normal state having a first width W**1**. FIG. **18** shows the diamond shaped bead **90** in a deformed state having a second width W**2** that is less than the first width W**1**. FIG. **19** shows a random shaped bead **90** in a normal state having a first width W**1**. FIG. **20** shows the random shaped bead **90** in a deformed state having a second width W**2** that is less than the first width W**1**. The desired deformation shape may determine the shape of the bead **90**.
(42) FIGS. **21** and **22** show an equivalent structure **405** to the structures shown above and for example in FIGS. **11-12**. Specifically, the first and second composition layers **350**, **360** are at a temperature T**1** in FIG. **21**, and T**2** that is greater than T**1** in FIG. **22**. The controlled thermal expansion shown in FIG. **22** results from the composition layers being integrally connected. That is, the first and second composition layers **350**, **360** bend together in a predictable and controlled way. That is, the controlled thermal expansion of the first and second composition layers **350**, **360** in the disclose embodiments provides for controlled manipulation of the airfoil disclosed herein.
(43) As can be appreciated, utilizing the above disclosed configurations to form the airfoil **10**, the camber of the airfoil may be selectively increased or decreased to change flow characteristics around it, e.g., to modify lift and drag, by applying thermal input to the materials, e.g., along the outer boundary **80** of the base **70** or, within one or more of the bead voids **100**. That is, driving current across the thermoelectric junction **150** in a first direction may increase camber and driving the current across the thermoelectric junction **150** in a second direction may decrease camber. Thus, a controllable airfoil may be obtained without the need for a movable part.
(44) The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or airfoils, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element airfoils, and/or groups thereof.
(45) Those of skill in the art will appreciate that various example embodiments are shown and described herein, each having certain features in the particular embodiments, but the present disclosure is not thus limited. Rather, the present disclosure can be modified to incorporate any number of variations, alterations, substitutions, combinations, sub-combinations, or equivalent arrangements not heretofore described, but which are commensurate with the scope of the present disclosure. Additionally, while various embodiments of the present disclosure have been described, it is to be understood that aspects of the present disclosure may include only some of the described embodiments. Accordingly, the present disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

Claims

1. An airfoil comprising: a composition gradient defining a first coefficient of thermal expansion (CTE) and a second (CTE) that differs from the first coefficient of thermal expansion; and a thermoelectric junction operationally coupled to the composition gradient, wherein the composition gradient is formed of either of a plurality of dissimilar metals or of plastic with fillings or fibers; a base formed by the composition gradient defining the first coefficient of thermal expansion and the second coefficient of thermal expansion that differs from the first coefficient of thermal expansion, so that: the base defines an outer boundary and beads within the outer boundary, each of the beads has a bead void, and each of the beads includes: first and second perimeter segments that are opposite each other and formed to define the first CTE; and third and fourth perimeter segments that are opposite each other, adjacent to the first and second perimeter segments, and formed to define the second CTE; and the thermoelectric junction is provided around the outer boundary or in one or more of the bead voids.
2. The airfoil of claim 1, wherein: each perimeter segment has a radial inner portion and a radial outer portion; the radial inner portion of the first and second perimeter segments is formed to define the first CTE and the radial outer portion of the first and second perimeter segments is formed to define the second CTE; and the radial inner portion of the third and fourth perimeter segments is formed to define the second CTE and the radial outer portion of the third and fourth perimeter segments is formed to define of the first CTE.
3. The airfoil of claim 1, wherein: adjacent ones of the beads are interconnected to form a lattice.
4. The airfoil of claim 1, wherein: the outer boundary defines a first outer end and a second outer end, wherein the first and second outer ends are opposite each other, and the base includes a top elastomer layer that is disposed against the first outer end of the outer boundary and a bottom elastomer layer that is disposed against the second outer end of the outer boundary.
5. The airfoil of claim 1, wherein the base includes an elastomer segment that extends from each of the beads that are located along the outer boundary of the base, so that adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.
6. The airfoil of claim 1, wherein: the base includes a support material that forms a support structure that defines the outer boundary of the base and a plurality of base voids, wherein each of the plurality of base voids is lined with one of the beads.
7. The airfoil of claim 6, wherein: the support material differs from the bead.
8. The airfoil of claim 1, wherein: the beads define an oval or diamond shape.
9. The airfoil of claim 1, wherein: the thermoelectric junction is a Peltier airfoil.
10. The airfoil of claim 1, wherein the composition gradient is formed of a first material having the first CTE and a second materials having the second CTE, and one or both of the first and second materials is a bistable metal, alloy or composite.