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62/118,823 20 February 2015 (20.02.2015) US(71) Applicant: **PRESIDENT AND FELLOWS OF HARVARD COLLEGE** [US/US]; 17 Quincy Street, Cambridge, Massachusetts 02138 (US).

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[Continued on next page]

(54) Title: HYBRID DIMPLE-AND-VOID AUXETIC STRUCTURES WITH ENGINEERED PATTERNS FOR CUSTOMIZED NPR BEHAVIOR

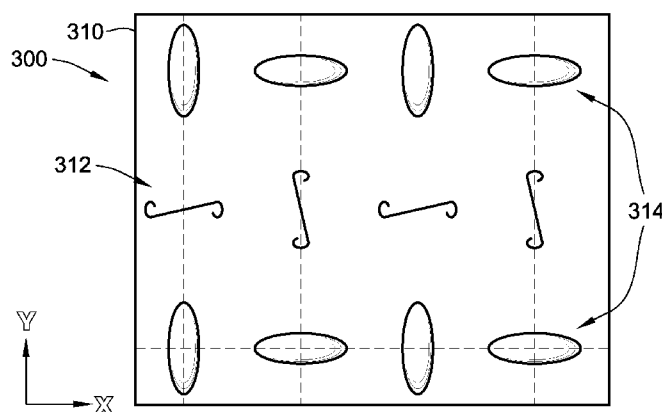


FIG. 3

(57) Abstract: Auxetic structures, low porosity auxetic sheets, systems and devices with auxetic structures, and methods of using and methods of making auxetic structures are disclosed. An auxetic structure is disclosed which includes an elastically rigid body with a plurality of apertures extending through the elastically rigid body and a plurality of protrusions projecting from the elastically rigid body. The apertures and protrusions are arranged in an engineered pattern, such as an array of rows and columns. The apertures are cooperatively configured with the protrusions to provide a predefined porosity while exhibiting stress reduction through negative Poisson's Ratio (NPR) behavior under macroscopic planar loading conditions. In some embodiments, the protrusions, which are elliptical or semispherical dimples, are interposed in square or hexagonal patterns with the apertures, which are S-shaped through slots or circular boreholes.



KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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(88) Date of publication of the international search report:

1 September 2016

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/012768

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B32B 3/10 (2016.01)

CPC - B32B 3/10; C08J 5/18 (2016.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - A41D 31/00; B32B 3/10, 3/12, 3/24, 3/26, 5/18, 7/02; C08J 5/18 (2016.01)

CPC - A41D 31/00; B32B 3/10, 3/12, 3/26, 5/18, 7/02; C08J 5/18; F23R 3/002; Y10T 428/24314 (2016.02)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 264/171.1; 428/136 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Patbase, Google Patents, Google, Google Scholar

Search terms used: auxetic, negative poisson's ratio, NPR, elastic, rigid, rows, columns, array, dimple, sphere, void, hole, aperture, cavity, metal, load, sheet, protrusion, depression

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/0021167 A1 (PLANT) 26 January 2012 (26.01.2012) entire document	1-51
A	WO 2014/151045 A1 (PRESIDENT AND FELLOWS OF HARVARD COLLEGE et al) 25 September 2014 (25.09.2014) entire document	1-51
A	US 2011/0059291 A1 (BOYCE et al) 10 March 2011 (10.03.2011) entire document	1-51
A	WO 2014/197059 A1 (PRESIDENT AND FELLOWS OF HARVARD COLLEGE et al) 11 December 2014 (11.12.2014) entire document	1-51

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 April 2016

Date of mailing of the international search report

03 MAY 2016

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/012768

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See supplemental page

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-51

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I, claims 1-51 are drawn to an auxetic structure.

Group II, claims 52-63 are drawn to a method of fabricating an auxetic structure

The inventions listed in Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, an auxetic structure comprising a plurality of apertures, the plurality of apertures being arranged in a first array of rows and columns, a plurality of protrusions, the plurality of protrusions being arranged in a second array of rows and columns, wherein the plurality of apertures is cooperatively configured with the plurality of protrusions exhibiting a negative Poisson's Ratio (NPR) behavior under macroscopic planar loading conditions, are not present in Group II; and, the special technical features of Group II, a method of fabricating an auxetic structure comprising receiving design values for predetermined design requirements of the auxetic structure, determining a maximum allowable stress value, and determining a unit cell arrangement, are not present in Group I.

Groups I and II share the technical features of an auxetic structure comprising an elastically rigid body, a plurality of apertures/slots, a plurality of protrusions/dimples, and a porosity.

However, these shared technical features do not represent a contribution over the prior art. Specifically, US 2012/0021167 A1 to Plant teaches of an auxetic structure (Para. [0088] regarding auxetic) comprising an elastically rigid body (Fig. 8; Para. [0002] regarding an energy absorbing material which is both lightweight and flexible...while still being able to dissipate and absorb shock loads), a plurality of apertures/slots (see apertures in Fig. 8 at section B-B), a plurality of protrusions/dimples (see upper and lower protrusions in Fig. 8 at section B-B; see also Fig. 9 where protrusions curve up and down at top most and lower most surface), and a porosity (see Figs. 8 and 9, where the structure is provided with a porous structure).

Since none of the special technical features of the Groups I-II inventions are found in more than one of the inventions, unity is lacking.