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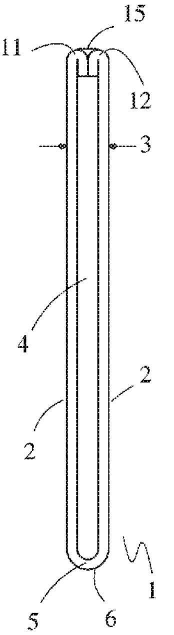
(54) Title: HEAT EXCHANGER TUBE

FIG. 1E



(57) Abstract: A flat tube for a heat exchanger is fabricated from a single sheet of metal material. The sheet of metal material has a first edge and a second edge, which are arranged adjacent to one another between a pair of broad walls of the tube. Flat sections extend from the edges and are disposed against one another. A pair of rounded walls arranged at an end of the tube connect the flat sections to the broad walls, and are joined by a weld bead within a space bounded by the outer surfaces of the rounded walls.

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HEAT EXCHANGER TUBE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This application claims priority to United States Provisional Patent Application No. 62/541,950 filed on August 7, 2017, the entire contents of which are hereby incorporated by reference herein.

BACKGROUND

[0002] Heat exchangers are typically constructed using thin metal structures through which fluids are conveyed. In an ongoing attempt to minimize both cost and weight, the thickness of the materials used to construct these structures are continuously being reduced. Such a reduction in material thickness can also, however, have the undesirable effect of decreasing the durability of the heat exchangers.

[0003] The aforementioned problem is particularly seen in the tubes used in vehicular heat exchangers such as radiators, condensers, and the like. Such heat exchanger tubes are often flat tubes constructed of thin aluminum alloy materials. When such a heat exchanger is arranged at the front of a vehicle, the outwardly facing ends of the tubes can be exposed to rocks and other debris. The impingement of such objects onto the exposed ends of the tubes can result in a the tube wall being breached, leading to a failure of the heat exchanger necessitating its replacement.

[0004] Tubes of this type are commonly constructed from a single sheet of material that is formed into the tube shape. In the forming of the tube, the ends of the sheet are typically brought together and butt welded to each other to form the closed tube wall boundary. In such a construction, the tube has a uniform wall thickness, which must be selected to be large enough to provide the requisite durability when exposed to the rocks and the like.

[0005] Several alternatives to the conventional welded tube construction are disclosed in United States published patent application no. 2009/0218085. In these alternative constructions, a brazed heat exchanger tube is constructed of one of more sheets of material, with overlapping layers of material being provided at the tube ends to increase the effective tube wall thickness at those ends and reinforce the tube. However, these constructions all require very complicated tube mills due to the many forming operations required, or the need to assemble multiple sheets of material, or both. In addition, these constructions all rely on only a brazed connection close the tube, and therefor lack the strength of a welded joint.

SUMMARY

[0006] According to some embodiments of the invention, a tube for a heat exchanger is fabricated from a single sheet of metal material. The tube has a pair of opposing, spaced apart broad walls that define a tube minor dimension, with an inner volume of the tube being provided between the pair of broad walls. A rounded wall of the tube bounds the inner volume at a first end of the tube, and connects the opposing broad walls at that end. The sheet of metal material has a first edge and a second edge, which are arranged adjacent to one another between the pair of broad walls. A first flat section extends from first edge, and a second flat section extends from the second edge. The first and second flat sections are disposed against one another. A second and a third rounded wall are arranged at a second end of the tube opposite the first end. The second rounded wall connects the first flat section to one of the broad walls, while the third rounded wall connects the second flat section to the other one of the broad walls. The second and third rounded wall sections are joined by a weld bead arranged within a space bounded by the outer surfaces of the second and third rounded walls.

[0007] In at least some such embodiments an outer surface of the rounded wall at the first end of the tube has a radius that is equal to the minor dimension of the tube, and an outer surface of each one of the second and third rounded walls has a radius that is equal to half of the tube minor dimension.

[0008] In at least some embodiments, the first flat section and the second flat section are connected to each other by a braze joint. In some such embodiments the first flat section is also connected to one of the broad walls by a braze joint, and the second flat section is also connected to the other of the broad walls by a braze joint.

[0009] In some embodiments, the tube inner volume is bounded at the second end by the first and second edges of the metal sheet. In other embodiments the tube inner volume is bounded at the second end by the second and the third rounded walls. In some embodiments the tube minor dimension is equal to four times the thickness of the metal sheet material.

[0010] In some embodiments, the weld bead is disposed entirely to one side of a plane that is tangent to both the outer surface of the second rounded wall and the outer surface of the third rounded wall. In other embodiments the weld bead extends on both sides of such a plane.

[0011] According to another embodiment of the invention, a method of making a heat exchanger tube includes the steps of: feeding a continuous flat sheet of metal material into a tube mill; hemming opposing edges of the flat sheet of metal material to form a pair of rounded ends; forming the sheet of metal material into a cylindrical shape, thereby bringing the rounded ends into contact with one another; creating a weld bead between the rounded ends; flattening the cylindrical shape; and separating the heat exchanger tube from the continuous flat sheet of metal material.

[0012] In at least some embodiments, the steps of hemming the edges, forming the cylindrical shape, and flattening the cylindrical shape occur in sequentially arranged forming stations of the tube mill. In some embodiments the weld bead is created in a welding station of the tube mill that is located immediately downstream of the forming station that creates the cylindrical shape.

[0013] In some embodiments, the step of flattening the cylindrical shape brings the edges of the sheet of metal material into contact with one another. In some such embodiments, braze joints are subsequently formed between the edges. In other embodiments, the edges remain spaced slightly apart from one another after the flattening step. In some such embodiments the tube is further flattened after having been separated from the continuous flat sheet of metal material, and in some embodiments an insert is inserted into the tube before the further flattening occurs. In some embodiments the tube is assembled into a heat exchanger core, and the step of further flattening is accomplished by compression of the core.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1A is an end view of a sheet of metal material after a forming step in the process of making a heat exchanger tube according to an embodiment of the invention.

[0015] FIG. 1B is an end view of the sheet of metal material after a subsequent forming step.

[0016] FIG. 1C is a detail end view of a portion of the sheet of metal material after the creation of a weld bead.

[0017] FIG. 1D is an end view of an at least partially finished heat exchanger tube according to an embodiment of the invention.

[0018] FIG. 1E is another end view of an at least partially finished heat exchanger tube according to an embodiment of the invention.

[0019] FIG. 2 is a schematic representation of a process for making a heat exchanger tube according to an embodiment of the invention.

[0020] FIG. 3 is a partial perspective view of a forming and welding station of a tube mill being used to produce a heat exchanger tube according to an embodiment of the invention.

[0021] FIG. 4 is a partial perspective view of a heat exchanger employing a heat exchanger tube according to an embodiment of the invention.

[0022] FIG. 5 is an end view of a heat exchanger tube according to an embodiment of the invention.

DETAILED DESCRIPTION

[0023] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the accompanying drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings.

[0024] A flattened heat exchanger tube 1 in sequential stages of fabrication is depicted in FIGs. 1A-E. The heat exchanger tube 1, as best seen in FIG. 1E, includes a pair of opposing, spaced apart broad walls 2. The spacing of the broad walls 2 defines a thickness of the tube 1, indicated by the dimension 3. This dimension is commonly referred to as the tube's "minor dimension", as it is substantially smaller than the width of the tube (i.e. the "major dimension" of the tube) as measured perpendicularly to the dimension 3 in the plane of FIG. 1E.

[0025] The broad walls 2 of the tube 1 can be provided as parallel flat walls, as depicted in FIG. 1E. Having the walls 2 be flat and parallel can provide certain advantages when the heat exchanger tube 1 is incorporated in a finished heat exchanger core, such as the one partially shown in FIG. 4. In certain embodiments, however, it may be advantageous to initially produce the heat exchanger tube with slightly curved walls 2, as depicted in FIG. 1D, for reasons that will be discussed hereafter.

[0026] The heat exchanger tube 1 can be at least partially formed within a tube mill 101, the operation of which is illustrated in schematic fashion in FIG. 2. A tube mill is generally known in the art as a machine that forms metal tubes from one or more continuous sheets of metal material through a succession of manufacturing stations arranged along the length of the mill. As depicted in FIG. 2, a single continuous sheet 110 of metal material is provided in the form of a coil 111 and is fed from that coil through the stations of the mill 101. The mill includes a first forming station 102, a second forming station 103, a seam welding station 104, a third forming station 105, and a cut-off station 106. It should be understood, however, that the stations of the tube mill can include various additional stations not mentioned above in addition to those specifically described herein without deviating from the invention.

[0027] In the first forming station 102, each of the opposing edges 7 and 8 of the sheet of metal material 110 are hemmed over with a 180° bend towards one side of the sheet, so that the profile of the sheet 100 upon exiting the station 102 is as depicted in FIG. 1A. Particularly, the ends of the sheet 110 at the exit of the station 102 each include a short flat section 9, 10 extending from the edges 7, 8 of the sheet and disposed parallel to and adjacent to the remaining flat portion of the sheet 110. Rounded walls 11, 12 connect the flat sections 9, 10 to that remaining flat portion. The lengths of the short sections 9, 10 can vary, but in general are a small fraction of the overall width of the sheet 110, and are typically on the order of one millimeter or several millimeters. In some especially preferable embodiments, the ends of the sheet 110 are hemmed completely or almost completely flat, as is the case in the embodiment depicted in FIG. 1A, so that the outer surfaces 13, 14 of the rounded end walls 11, 12 have a radius that is approximately equal to the thickness (indicated as the dimension "t" in FIG. 1A) of the sheet 110. In other embodiments, the flat sections 9, 10 are slightly spaced off of the remainder of the sheet, such that outer surfaces 13, 14 have a radius that is somewhat larger than the thickness of the sheet 110.

[0028] The forming of the ends 11, 12 within the forming station 102 is typically done using a series of rollers or other moving surfaces that engage the sheet 110 in order to deform or manipulate the sheet material. It may be preferable for the forming operation to be distributed into several stages, such as a stage that bends the ends of the sheet 110 through a first angle, such as for example a 90° angle, followed by another stage that folds the bent edge to be parallel to the remainder of the sheet 110. Consequently, it should be understood that the forming station 102 can correspond to a succession of independent forming operations that collectively transform the sheet of material 110 from a flat sheet into the form depicted in FIG. 1A. It should further be understood that the opposing edges 7, 8 can be hemmed concurrently within the forming station 102, or that one of the edges 7, 8 can first be hemmed and the other one of the edges can subsequently be hemmed, the forming station 102 being considered to constitute the entirety of those forming operations.

[0029] After exiting the first forming station 102, the sheet of material 110 enters a second forming station 103 wherein the flat sheet is rolled into a cylindrical profile as depicted in FIG. 1B. Particularly, the end walls 11, 12 are brought together so that the outer surfaces 13, 14 are brought into contact with one another. The entire sheet 110 thereby takes on a cylindrical shape. This forming operation can be performed using a series of opposed rollers that progressively deform the sheet 110, with a final set of rollers 112 (depicted in FIG. 3) bringing the end walls 11, 12 into contact and completing the cylindrical shape.

[0030] A seam welding station 104 is arranged immediately downstream of the second forming station 103 along the length of the tube mill 101, and the forming station 103 and welding station 104 can therefore be considered to be co-located as indicated in FIG. 2. Within the welding station 104, as shown in FIG. 3, a weld tip 113 is used to create a continuous weld seam 15 at the location where the rounded end walls 11, 12 of the sheet 110 are in contact. As can be seen in the detail view of FIG. 1C depicting that portion of the cylindrical tube profile exiting the welding station 104, the weld bead 15 is disposed within the valley that is naturally formed between the curved outer surfaces of the walls 11, 12. Having the weld bead so located can preclude the need to subsequently grind down the weld bead 15, as is often required in a conventional butt weld joint between two edges of a flat sheet.

[0031] After the welding station 104, the sheet 110, now in cylindrical form, passes through a third forming station 105 wherein the cylindrical shape is flattened to a shape such as that shown in FIG. 1D and/or FIG. 1E. The forming operation in station 105 can be performed by another series of rollers that engage the cylindrical surface of the sheet 110 at locations that are approximately 90° to either side of the welded joint in order to progressively flatten the cylindrical shape. As a result of this flattening operation, the sheet 110 takes on a flattened tube profile with a pair of opposing broad walls 2 that are joined at one end by the welded rounded ends 11, 12 and are joined at an opposing end by a single rounded wall 5.

[0032] The flattening of the cylindrical shape causes a rotation of the rounded walls 11 and 12, such that the short flat sections 9 and 10 are disposed against one another. The weld bead 15 remains intact during the flattening operation, but may be stretched somewhat by the rotation of the rounded walls.

[0033] A terminal station 106 of the tube mill 101 is configured as a cut-off station, where individual flat tubes 1 are severed from the continuous sheet 110. The individual flat tubes 1 can be in a finished form, as depicted in FIG. 1E, of they can be in a partially finished form, as depicted in FIG. 1D. In the finished form of 1E, the opposing broad walls 2 are flat and parallel with one another, and are spaced apart to define a tube minor dimension indicated with the reference number 3. The outer surface 6 of the rounded wall 5 has, in that case, a radius that is equal to half of the tube minor dimension 3, so that the rounded wall 5 spans a total arc length of 180°.

[0034] The tubes 1 can alternatively be cut off from the tube mill 101 in a partially finished form as shown in FIG. 1D. In that partially finished form, the opposing broad walls 2 are slightly arched, so that the spacing between the broad walls 2 is slightly larger at the centers of the broad walls than it is at either end of the broad walls. Such a tube shape can provide certain advantages in the subsequent assembly of the flat tube 1 into a heat exchanger.

[0035] FIG. 4 depicts a portion of a heat exchanger 200 using several tubes 1 according to an embodiment of the invention. The heat exchanger 200 includes a pair of opposing cylindrical headers 201 (only one is shown) with spaced tube slots extending along the length of the headers at a regular spacing to accommodate ends of the tubes 1. Corrugated fins 203 are arranged between adjacent ones of the tubes 1, and crests and troughs of the corrugated fins 203 are joined to the broad walls 2 of the tubes 101 by braze joints or similar metallurgical connections to ensure the efficient transfer of heat from a fluid flowing within the internal spaces 4 of the tubes 1 to another fluid (typically air) flowing over the outer surfaces of the tubes 1 and over the fins 203. It should be understood that, although cylindrical headers are depicted in the exemplary embodiment, a heat exchanger 200 could alternatively be constructed using flat headers, oval headers, or headers of other shapes.

[0036] In order to maximize the contact area between the broad surfaces 2 of the flat tubes 1 and the fins 201, and thereby to maximize the rate of heat transfer, it is especially desirable for the broad surfaces 2 to be flat and parallel to each other, as is depicted in FIG. 1E. Achieving such flatness within the tube mill 101 can be challenging however. It can therefore be particularly preferable for the tubes 1 to be delivered from the tube mill 101 in a form such as that shown in FIG. 1D, with the broad surface 2 having a slightly convex bow. In the assembly of the heat exchanger 200, the tubes 1 and fins 203 are commonly stacked into a matrix arrangement of alternating tubes and fins, bounded by a side plate 202 at the bottom and top of the stack. Compressive force is subsequently applied to the assembled stack through the side plates 202, which has the result of further flattening the tubes 1 into their final, desired shape of FIG. 1E. The headers 201 can then be assembled onto the tube ends, and the compressed core can be brazed (e.g. in a brazing furnace) into a monolithic structure.

[0037] The placement of the weld bead 15 within the valley formed by the contacting round surfaces 13, 14 allows for ease of assembly of the tube ends into the slots of the headers 201. In especially preferable embodiments, the weld bead 15 is entirely located to one side of a plane 16 (shown in FIG. 5) that is tangent to both surfaces 13 and 14. This allows for the smooth insertion of the tube ends into the slots. In addition, having the weld bead 15 fill that valley can provide for a better braze joint at the tube to header connection, since it is not necessary for the valley to be filled with braze alloy.

[0038] Producing the tubes 1 with a shape such as is shown in FIG. 1D can also be beneficial in cases where an internal insert 17 is desired to be present within the tubes 1. An end view of a tube 1 containing such an insert 17 is depicted in FIG. 5. The presence of inserts 17 can provide improved heat transfer rates within the tubes 1, as they increase the heat transfer coefficient by way of a smaller hydraulic diameter and increase the heat transfer surface area for the internal fluid. It is especially preferable for the inserts 17, when present, to be brazed to the tubes 1. The insert 17 is inserted into the tube 1 after the tube 1 has been produced in the tube mill 101 with a shape such as the one shown in FIG. 1D. Due to the slight outward bow of the broad walls 2, the frictional drag between the crests of the insert 17 and the inner surfaces of the broad walls 2 that would be experienced upon insertion of the insert 17 into the tube 1 can be greatly reduced, thereby simplifying the manufacturing process. The desirable good contact between the inserts 17 and the tube walls 2 can subsequently be achieved in the compression of the heat exchanger core, as described previously. The inserts 17 provide an additional functionality during such a compression in that they can serve as a hard stop for the deflection of the broad walls 2, preventing any inward collapse of the walls 2 which might otherwise result in poor braze joints between the fins 203 and the tubes 1.

[0039] As best seen in FIG. 1E, the tube 1 in its finished form provides a tube inner volume 4 between the broad walls 2. The tube inner volume 4 is bounded at one end by the rounded wall 5, and is bounded at the opposing end by the edges 7 and 8 of the original sheet material. As a result, the effective thickness of the tube wall at that end is substantially greater than the thickness “t” over the remainder of the tube. The tubes 1 are preferably assembled into the heat exchanger 200 in a common orientation, so that the rounded walls 11 and 12 are all arranged at one face of the heat exchange core. This allows for the installation of the heat exchanger 200 so that the ends 11 and 12 are outwardly facing. The increased effective thickness thereby provides additional structural reinforcement against any impingement by rocks and the like that may occur during operation of the heat exchanger 200, thereby allowing the tubes 1 to be constructed of thinner material without sacrificing heat exchanger durability.

[0040] Additional reinforcement of the tube at the end corresponding to the rounded walls 11 and 12 can further be achieved by having the contacting flat sections 9 and 10 brazed to each other during the brazing of the heat exchanger 200, so that a combined welded and brazed joint is achieved at that tube end. Such a braze joint can be readily achieved when the sheet material 110 is provided with a layer of braze cladding material on the side that becomes the external surface of the tube 1. This braze cladding layer is often provided in order to supply the necessary braze alloy for the joining of the fins 203 to the tubes 1, as well as for the joining of the tube ends to the headers 201. A strong, reinforced tube end can thereby be provided without requiring any additional braze material. The tube end can be further reinforced by the creation of braze joints between the flat sections 9, 10 and the inner surfaces of the broad walls 2, when a braze cladding layer is provided on both sides of the sheet 110.

[0041] Various alternatives to the certain features and elements of the present invention are described with reference to specific embodiments of the present invention. With the exception of features, elements, and manners of operation that are mutually exclusive of or are inconsistent with each embodiment described above, it should be noted that the alternative features, elements, and manners of operation described with reference to one particular embodiment are applicable to the other embodiments.

[0042] The embodiments described above and illustrated in the figures are presented by way of example only and are not intended as a limitation upon the concepts and principles of the present invention. As such, it will be appreciated by one having ordinary skill in the art that various changes in the elements and their configuration and arrangement are possible without departing from the spirit and scope of the present invention.

What is claimed is:

1. A heat exchanger tube fabricated from a single sheet of metal material, comprising:

a pair of opposing, spaced apart broad walls defining a tube minor dimension;

a tube inner volume provided between the pair of broad walls;

a first rounded wall bounding the tube inner volume at a first end of the heat exchanger tube to connect the pair of broad walls, an outer surface of the first rounded wall having a radius equal to the tube minor dimension;

a first edge and a second edge of the sheet of metal material arranged adjacent to one another between the pair of broad walls;

a first flat section extending from the first edge of the sheet of metal material and a second flat section extending from the second edge of the sheet of metal material, the first flat section and the second flat section disposed against one another;

a second rounded wall arranged at a second end of the heat exchanger tube opposite the first end to connect the first flat section and a first one of the pair of broad walls, an outer surface of the second rounded wall having a radius equal to half of the tube minor dimension;

a third rounded wall arranged at the second end of the heat exchanger tube to connect the second flat section and a second one of the pair of broad walls, an outer surface of the third rounded wall having a radius equal to half of the tube minor dimension; and

a weld bead joining the second and third rounded walls, the weld bead being arranged within a space bounded by the outer surface of the second rounded wall and the outer surface of the third rounded wall.

2. The heat exchanger tube of claim 1, wherein the first flat section and the second flat section are connected by a braze joint.

3. The heat exchanger tube of claim 2, wherein the first flat section is additionally connected to the first one of the pair of broad walls by a braze joint and wherein the second flat section is additionally connected to the second one of the pair of broad walls

by a braze joint.

4. The heat exchanger tube of claim 1, wherein the tube inner volume is bounded at the second end by the first and second edges of the sheet of metal material.

5. The heat exchanger tube of claim 1, wherein the sheet of metal material has a thickness and wherein the tube minor dimension is four times that thickness.

6. The heat exchanger tube of claim 1, wherein the tube inner volume is bounded at the second end by the second and the third rounded walls.

7. The heat exchanger tube of claim 1, wherein the weld bead is disposed entirely to one side of a plane that is tangent to both the outer surface of the second rounded wall and the outer surface of the third rounded wall.

8. A method of making a heat exchanger tube, comprising:

feeding a continuous flat sheet of metal material into a tube mill;

hemming opposing edges of the flat sheet of metal material in a first forming station of the tube mill to form first and second rounded ends;

forming the sheet of metal material into a cylindrical shape, thereby bringing the first and second rounded ends into contact with one another, in a second forming station of the tube mill;

creating a weld bead between the first and second rounded ends;

flattening the cylindrical shape in a third forming station of the tube mill; and

separating the heat exchanger tube from the continuous flat sheet of metal material in a cut-off station of the tube mill.

9. The method of claim 8, wherein the step of flattening the cylindrical shape brings the edges of the sheet of metal material into contact with one another.

10. The method of claim 9, further comprising forming braze joints between the edges of

the sheet of metal material.

11. The method of claim 10, further comprising forming braze joints between a first one of the original edges of the sheet of metal material and a first broad outer wall of the tube and between a second one of the original edges of the sheet of metal material and a second broad outer wall of the tube.

12. The method of claim 8, wherein the weld bead is created in a welding station of the tube mill, the welding station of the tube mill located immediately downstream of the second forming station within the tube mill.

13. The method of claim 8, further comprising:

inserting an insert into the heat exchanger tube; and

further flattening the heat exchanger tube after insertion of the insert.

14. The method of claim 13, wherein the step of further flattening the heat exchanger tube occurs by compressing a heat exchanger core into which the heat exchanger tube has been assembled.

15. A heat exchanger tube obtained by the process of claim 8.

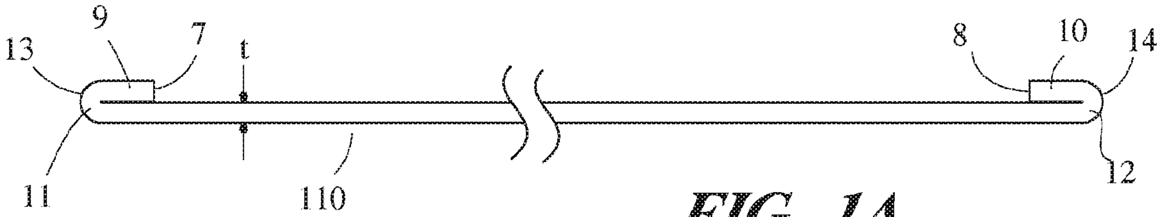


FIG. 1A

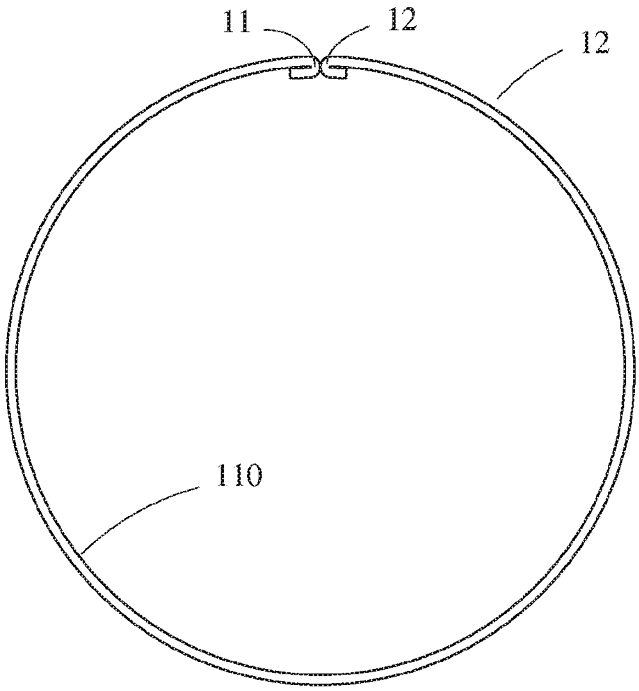


FIG. 1B

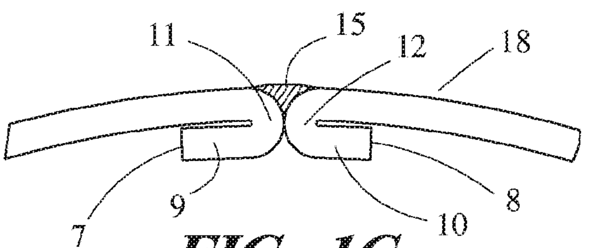


FIG. 1C

FIG. 1E

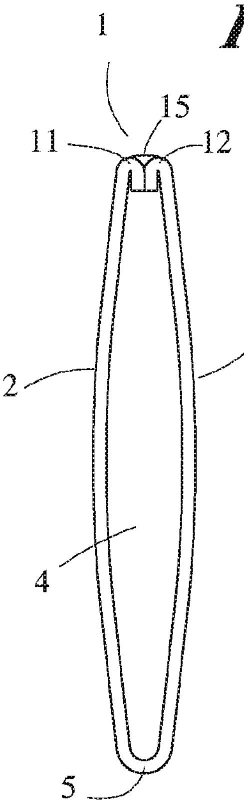
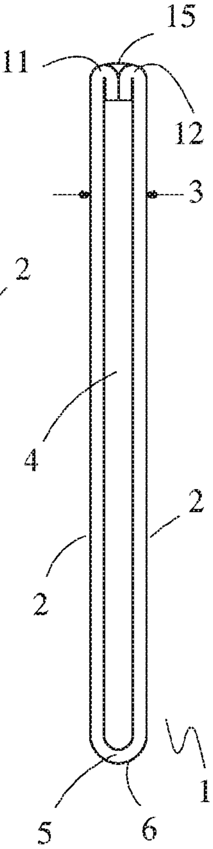


FIG. 1D



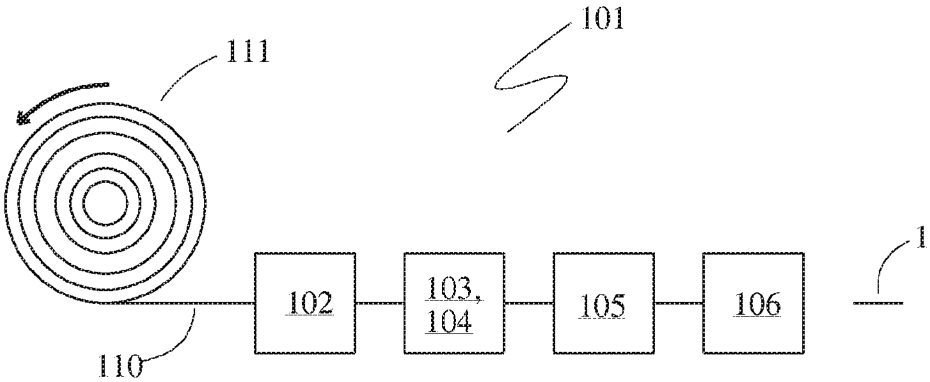


FIG. 2

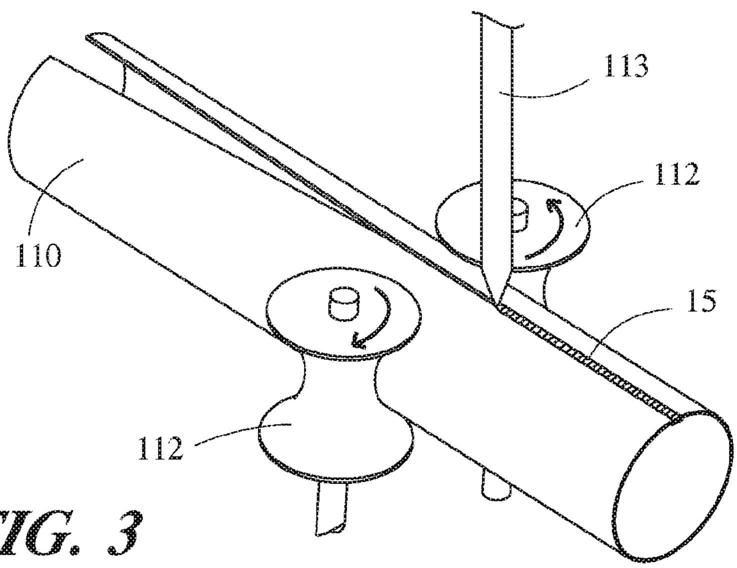
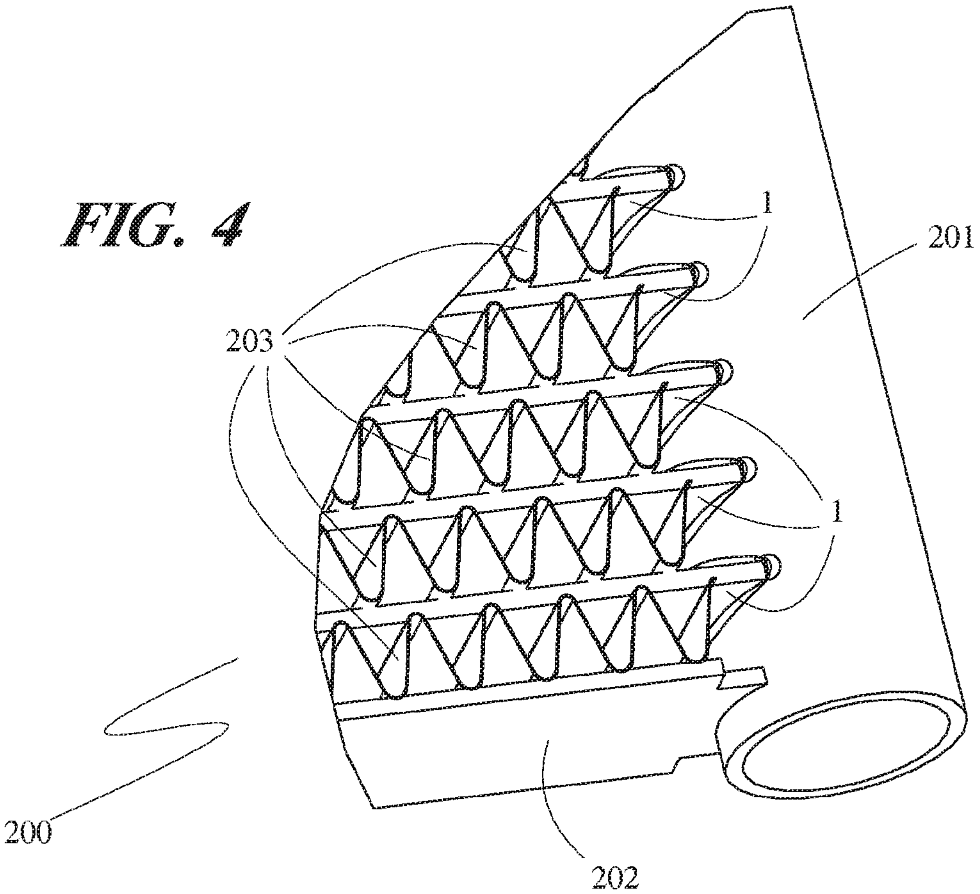


FIG. 3

FIG. 4



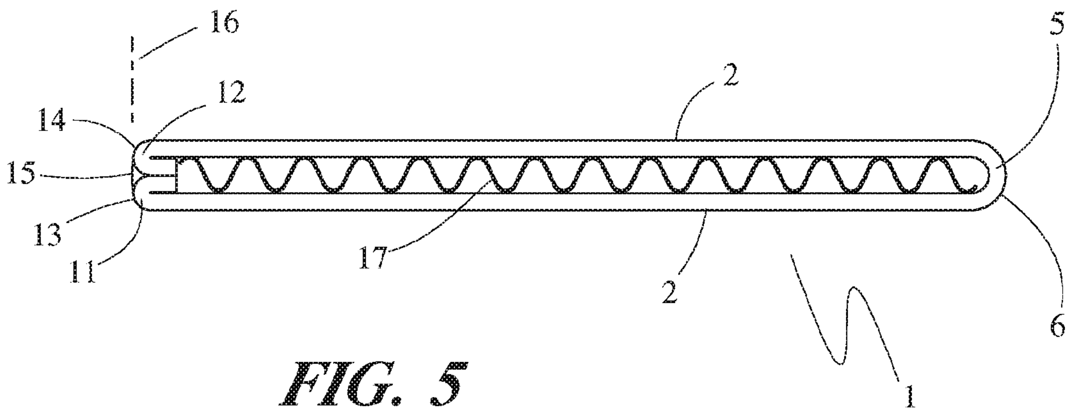


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/045512

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F28F 1/02; B21C 37/06; B21C 37/08; F28F 1/00 (2018.01)

CPC - F28F 1/02; B21C 37/06; B21C 37/08; F28F 1/00; F28F 1/022; F28F 2225/04 (2018.08)

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)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 165/177; 165/180; 165/181 (keyword delimited)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,186,250 A (OUCHI et al) 16 February 1993 (16.02.1993) entire document	1, 2, 4-7
A	US 4,558,695 A (KUMAZAWA et al) 17 December 1985 (17.12.1985) entire document	1-15
A	US 2005/0006082 A1 (BROST et al) 13 January 2005 (13.01.2005) entire document	1-15
A	US 2006/0201665 A1 (YU et al) 14 September 2006 (14.09.2006) entire document	1-15

☐ 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	Date of mailing of the international search report
21 September 2018	10 OCT 2018

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