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Flexible mat with fluid conduit, method of manufacture thereof and apparatus for the manufacture thereof

Abstract

The present invention provides a flexible mat with fluid conduit, methods of manufacture thereof and apparatus for the manufacture thereof. In an embodiment, the mat comprises a base layer, one or more fluid conduits and a thermoplastic bonding tape that attaches the fluid conduits to the base layer. The base layer can be a textile fabric, mesh or netting, or a flat flexible sheet. The base layer is preferably also formed of a thermoplastic layer. The fluid conduits can carry heated or cooled fluid, such as water, that can be used for heating or cooling an environment in which the device is deployed. For example, the device can be used for heating or cooling in a greenhouse environment. The fluid conduits can additionally or alternatively carry irrigation fluids, such as water or treated water, for irrigating plants and crops. The fluid conduits can additionally or alternatively carry gases, such as carbon dioxide (CO₂) or carbon dioxide mixed with other gasses, for treating plants and crops.

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Background/Summary

(1) This application claims priority of U.S. Provisional Application No. 62/893,773, filed Aug. 29, 2019, the entire content of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

(1) The present invention relates to the field of flexible mats with fluid conduit which can be used for heating and cooling. More particularly, the present invention relates to flexible mats with fluid conduit and to methods of, and apparatus for, the manufacture of such mats.

(2) Heating and cooling devices are useful in myriad situations. For example, heating and cooling devices can be used for heating and cooling in greenhouses and other environments. In a greenhouse environment, heating and cooling can be accomplished using fluid conduits that carry heated or cooled fluid, which then heats or cools interior spaces of the greenhouse. The fluid carrying conduits may be present in a mat that can, for example, be laid on the floor of a greenhouse or placed on raised planting beds. As another example, a mat carrying heated fluid can be used in cold outdoor environments to melt ice or snow from walkways or driveways.

(3) It is desired to provide improved flexible mats with fluid conduit which can be used for heating or cooling. It is further desired to provide improved methods and apparatus for the manufacture of such mats.

SUMMARY OF THE INVENTION

(4) The present invention provides a flexible mat with fluid conduit, methods of manufacture thereof and apparatus for the manufacture thereof. In accordance with an embodiment, a flexible mat with fluid conduit is provided. The mat comprises: a flexible base layer; a plurality of fluid conduits arranged substantially in parallel to each other and adjacent to the base layer; and a plurality of strips of tape arranged substantially in parallel to each other and substantially orthogonal to the fluid conduits. The strips of tape are bonded to the base layer. For example, the tape may be thermoplastically welded to the base layer.

(5) One or more of the plurality of fluid conduits may be configured to carry heat transfer fluid to form part of a closed recirculating environmental control system. Alternatively or additionally, one or more of the plurality of fluid conduits may be configured to carry irrigation water. For example, the fluid conduits may have perforations or may accept irrigation fittings. Alternatively or additionally, one or more of the plurality of fluid conduits may be configured to carry gas, e.g., carbon dioxide gas. Moreover, the plurality of fluid conduits may be configured to carry two or more fluids such as heat transfer fluid, irrigation water, and gas.

(6) In accordance with an embodiment of the present invention, a method of manufacture of a flexible mat with fluid conduit is provided. The method includes: placing a plurality of fluid conduits oriented substantially parallel to each other against a flexible base layer; and applying strips of thermoplastic bonding tape over the fluid conduits. The strips of thermoplastic bonding tape are oriented substantially orthogonal to the fluid conduits. The strips of thermoplastic bonding tape may be applied by welding the strips of thermoplastic bonding tape to the base layer. The fluid conduits are captured between the tape and the base layer.

(7) The base layer may be thermoplastic. Applying of the strips of thermoplastic bonding tape may include: unrolling the bonding tape from a roll of bonding tape; and pressing a heat sealing bar against the strips of thermoplastic bonding tape.

(8) Welding the strips of thermoplastic bonding tape to the base layer may include successively heating portions of each tape strip and immediately bringing the heated portions of thermoplastic bonding tape into contact with the base layer. Applying strips of thermoplastic bonding tape may include: unrolling the bonding tape from a roll of bonding tape; applying heated air to the bonding tape; and pressing the bonding tape into contact with the base material layer using a roller. Cooling

air may be applied to the roller.

(9) The method may also include: unwinding the base layer from a first roll; and winding the base layer with the fluid conduits attached into a second roll. A shaft for the second roll may be driven according to increments, where each increment determines spacing between the strips of thermoplastic bonding tape.

(10) In accordance with an embodiment of the present invention, an apparatus for the manufacture of flexible mat with fluid conduit is provided. The apparatus comprises: a substantially flat plate configured to support at least a portion of a flexible sheet of base layer; a plurality of guides configured to position each of a plurality of fluid conduits parallel to each other and over the plate; a holder configured to hold a roll of thermoplastic bonding tape; a heating element configured to apply heat to the thermoplastic bonding tape; and a pressure applicator configured to press the bonding tape into contact with the base layer.

(11) A heat sealing bar may comprise the heating element. The pressure applicator may press the heat sealing bar into contact with the thermoplastic bonding tape, thereby pressing the bonding tape into contact with the base layer.

(12) The pressure applicator may comprise: a shuttle that is movable with respect to the plate in a direction that is substantially orthogonal to the orientation of the fluid conduits; and a roller attached to the shuttle and configured to apply bonding tape over the fluid conduits thereby pressing the bonding tape into contact with the base layer. The shuttle may be configured to hold a roll of thermoplastic bonding tape. The apparatus may be configured such that, while the shuttle is in motion, the bonding tape is unrolled from the roll of bonding tape, the bonding tape is heated, and the bonding tape is pressed into contact with the base layer using the roller. A suction cup lifter may be attached to the shuttle and configured to lift the tape. A cutter may be configured to cut the tape.

(13) The apparatus may also include: a first rotatable shaft configured to unwind a roll of the base layer; and a second rotatable shaft configured to wind the base layer with the fluid conduits attached into a roll. A plurality of spools may be configured to hold the plurality fluid conduits so that the fluid conduits are drawn into the plurality of guides upon rotation of the second rotatable shaft. The second rotatable shaft can be motor driven. A braking mechanism may be coupled to the first rotatable shaft for maintaining tension in the base layer. The apparatus may be configured to rotate the first rotatable shaft between the application of successive strips of the bonding tape. An amount of the rotation may determine spacing of the successive strips of bonding tape.

(14) These and other aspects of the present invention are described herein.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The present invention is described with respect to particular exemplary embodiments thereof and reference is accordingly made to the drawings in which:

(2) FIG. 1 illustrates a top view of a flexible mat with fluid conduit in accordance with an embodiment of the present invention;

(3) FIG. 2 illustrates a cross-sectional view of the flexible mat with fluid conduit of FIG. 1 in accordance with an embodiment of the present invention;

(4) FIG. 3 illustrates a top view of a mat with fluid conduit in accordance with an alternative embodiment of the present invention;

(5) FIG. 4 illustrates a front view of an apparatus for the manufacture of a mat with fluid conduit in accordance with an embodiment of the present invention;

(6) FIG. 5 illustrates a side view of an apparatus for feeding of material in connection with the manufacture of a mat with fluid conduit in accordance with an embodiment of the present

invention;

(7) FIG. 6 illustrates a top view of an apparatus for feeding of material in connection with the manufacture of a mat with fluid conduit in accordance with an embodiment of the present invention;

(8) FIG. 7 illustrates a front view of an apparatus for the manufacture of a mat with fluid conduit, the apparatus including a print head, weld tape meter and cooling air jet in accordance with an embodiment of the present invention;

(9) FIG. 8 illustrates a side view of an apparatus for feeding of material in connection with the manufacture of a mat with fluid conduit, the apparatus having conduit rollers in accordance with an embodiment of the present invention;

(10) FIG. 9 illustrates a perspective view of an apparatus for the manufacture of a mat with fluid conduit in accordance with an embodiment of the present invention;

(11) FIG. 10 illustrates a perspective view of an apparatus for the manufacture of a mat with fluid conduit in accordance with an alternative embodiment of the present invention; and

(12) FIG. 11 illustrates a perspective view of a pneumatic brake assembly and finished material roll speed controller assembly in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

(13) A flexible mat with fluid conduit is described. In accordance with an embodiment, such a mat comprises a base layer, one or more fluid conduits and a thermoplastic bonding tape that attaches the fluid conduits to the base layer. The thermoplastic bonding tape may also be referred to as “weld tape.” The base layer can be, for example, a textile fabric, mesh or netting, or a flat flexible sheet. The base layer is preferably also formed of a thermoplastic material. The fluid conduits are also preferably flexible. The conduits can carry heat transfer fluid, such as heated or cooled water, that can be used for heating or cooling an environment in which the device is deployed. For example, the device can be used for heating or cooling in a greenhouse environment. The fluid conduits can additionally or alternatively carry irrigation fluids, such as water or treated water, for irrigating plants and crops. Such treated irrigation water can include water mixed with fertilizer and/or water infused with carbon dioxide (CO₂) gas. The fluid conduits can additionally or alternatively carry gases, such as carbon dioxide (CO₂) or carbon dioxide mixed with other gasses, for treating plants and crops.

(14) A method of manufacture of a flexible mat with fluid conduit is also described. In accordance with an embodiment, such a method comprises placing a plurality of fluid conduits oriented substantially parallel to each other against a base sheet material and applying strips of thermoplastic bonding tape over the fluid conduits. The strips of thermoplastic bonding tape can be oriented substantially orthogonal to the fluid conduits. The strips of thermoplastic bonding tape can be applied by welding the strips of thermoplastic bonding tape to the base layer. The tape is thereby adhered to the base layer and the fluid conduits are captured between the tape and the base material. In an embodiment, a heat sealing bar can be pressed against the strips of thermoplastic bonding tape. In another embodiment, the tape can be heated and a roller can be used to press the heated tape onto the base material. The base material is also preferably a thermoplastic material; in this case, the heat sealing bar can be used to heat portions of the base material or the base material can be heated just prior to being brought into contact with the bonding tape.

(15) An apparatus for the manufacture of flexible mat with fluid conduit is also described. In accordance with an embodiment, such an apparatus attaches fluid conduit to a base sheet material in a customizable configuration. The apparatus is configured to unwind a roll of the base material that is mounted to a rotatable shaft and to pass the material over a substantially flat plate. The apparatus is configured to simultaneously unwind fluid conduit from a plurality of spools and to position a plurality of the fluid conduits, one for each spool, over the plate and the base material. The fluid conduits are preferably positioned substantially parallel to each other at predetermined and adjustable spacing. The apparatus is configured to apply a strip of thermoplastic bonding tape

over the fluid conduits. The strip of thermoplastic bonding tape can be oriented substantially orthogonal to the fluid conduits. The apparatus is configured to apply heat to the thermoplastic bonding tape and to bring the tape into contact with the base material so that the tape is welded to the base layer and the fluid conduits are captured between the tape and the base layer. This can be accomplished, in part, by continuously applying heat energy to the tape in the form of heated air while the tape is being unrolled and pressed onto the base material. The apparatus may comprise a roller and a substantially flat plate. The roller can be used to press the heated tape onto the base material while the base material is supported by the substantially flat plate. Alternatively, a heat sealing bar can be used to press the tape onto the base material while the base material is supported by the substantially flat plate. The heat sealing bar can include a heating element that heats the tape.

(16) The base layer is also preferably a thermoplastic material. The apparatus is can be configured to heat portions of the base layer being brought into contact with the bonding tape.

(17) The tape can be cut into strips. The length of the strips is approximately equal to, or slightly greater than, the width of the base material. To accomplish cutting the tape into strips, the tape can be cut near the edge of the base material each time a portion of the tape has been adhered across the width of the base material.

(18) The tape can be cut into strips. As used herein, the term “strip” has its ordinary meaning, i.e. long and narrow. The length of the strips is approximately equal to, or slightly greater than, the width of the base material. To accomplish cutting the tape into strips, the tape can be cut near the edge of the base material each time a portion of the tape has been adhered across the width of the base material.

(19) The material can then be removed from the rewind shaft for further processing and sale. Such further processing can include cutting the material to desired lengths and adding couplings and/or fittings to the fluid conduits.

(20) The mat with fluid conduit attached, as described herein, can be used in a variety of applications. For example, the mat can be used in the field of horticulture. Such uses can include heating and/or cooling greenhouse environments, delivering irrigation water and/or delivering gas (e.g., carbon dioxide) to the greenhouse environment. In a particular horticultural application, the mat can be used to deliver irrigation water to a flood table. In this case, the mat can lay at the bottom of a plant tray with containers holding the plants placed on top of the mat. In this case, the mat can provide irrigation water that is used to periodically flood the plant tray. The mat may also deliver carbon dioxide gas to the greenhouse environment. In an embodiment, the base layer can comprise a fluid impermeable material so that the mat itself can serve as the bottom of the plant tray. In such an embodiment, the mat may be held under tension by a table frame or may be supported (e.g., by an expanded metal table top) in order to support the weight of the water and plants. In such an embodiment, sides for the plant tray can be attached to the table frame and/or directly to the mat. The mat can also be used in outdoor horticultural environments. For example, the mat can be used to prevent freezing and/or to deliver irrigation in such outdoor environments. In a particular example, the mat can be used in connection with sports fields. In an embodiment, the mat can be installed beneath live turf grass and used to apply heat to avoid freezing of the turf grass or to melt snow and ice from the turf grass. In such an embodiment, the mat can be used to deliver irrigation water to the turf grass (i.e. by sub-irrigation). In a further embodiment, the mat may be configured to accept greenhouse hoop structures where the hoops are configured to support a poly greenhouse cover. For example, one or both edges of the mat may have attached tubes or loops or other fittings that are configured to attach at or near the ends of the greenhouse hoops. In this case, the mat can serves as a floor for a “hoop house” or “poly tube” type of greenhouse.

(21) The mat with fluid conduit attached, as described herein, can be used in additional applications. For example, the mat can be used for heating and/or cooling zoo animal or livestock animal enclosures. As another example, the mat can be employed in radiant floor heating systems

in buildings, such as homes, offices and factories. In still another embodiment, the mat can be used to melt snow and ice present on outdoor surfaces such driveways or walkways. This can be accomplished by installing the mat beneath the outdoor surface or by laying the mat on the outdoor surface. It will be apparent that the above applications are intended to be exemplary and that additional applications are possible.

(22) FIG. 1 illustrates a mat **100** with fluid conduit **102** in accordance with an embodiment of the present invention. The conduit **102** can be any type of tubing or conduit, but is preferably a flexible plastic or polymer. Examples of suitable conduit include, but are not limited to, irrigation tubing (which may be perforated and/or capable of accepting barbed irrigation fittings), gas tubing (which may or may not be gas-permeable), tubing suitable for carrying various types of fluids, such as water and gas, and tubing made from materials such as polyvinyl chloride, polypropylene, polypropene, polyethylene, linear low-density polyethylene, high density polyethylene, synthetic rubber, high-density synthetic rubber, such as Ethylene Propylene Diene Monomer rubber (EPDM), cross-linked polyethylene (PEX) and so forth.

(23) The mat **100** further comprises a sheet material **104**, which can be, for example, a textile fabric, mesh, netting, or flat flexible sheet. The material **104** serves as a base layer for the mat **100**. The base layer **104** has a width **106** and a length **108**. The base material **104** is preferably obtained in rolls of various widths, which can be in standard sizes, such as 4, 6, 8, 10 or 12 feet, for example. The length **108** can therefore be any dimension up to a maximum length available in rolled form (though rolls can be spliced together at the ends for longer lengths or along their sides for wider widths).

(24) The base material **104** can be water permeable, or water impermeable, depending on the application. Suitable base materials include but are not limited to weed-blocking and/or light-blocking fabrics, which can be obtained in various colors including white for reflecting light or black for absorbing light. Specific examples include plastic netting or mesh, which can allow for the passage of debris such as dirt or other planting substrates, or polymer fabrics. In a preferred embodiment, the base material is thermoplastic. In an embodiment, the base material **104** is configured to be heat insulating. For example, the base material **104** may be formed from a thick plastic material which serves as an insulator and which may also be thermoplastic. Alternatively, the base material **104** may include a laminate having an insulating layer (e.g., a closed cell insulation material) and one or more other layers (e.g., a thermoplastic mesh). Such an insulating layer may be attached to one side of the thermoplastic layer before or after the conduits are attached to the other side of the thermoplastic layer. Still further, such an insulating layer may be attached over the conduits after the conduits are attached to the material **104**.

(25) The fluid conduit **102** is attached to the base material **104** by bonding tape **110**. The bonding tape **110** is preferably a thermoplastic, such as polyethylene, polypropylene or polyvinyl chloride. In this case, the tape **110** is can be welded to the base material by heating the tape prior to applying the tape over the fluid conduits **102** or by heating the tape after the tape is applied over the fluid conduits. In either case, the heated tape is preferably pressed onto the base material **104** thereby welding the tape to the base material **104**.

(26) FIG. 2 illustrates a cross-sectional view of the mat **100** with fluid conduit **102** of FIG. 1 in accordance with an embodiment of the present invention. As shown in FIG. 2, the fluid conduits **102** are positioned between the base material **104** and the tape **110**. Alternatively or additionally to thermoplastic bonding, the tape **110** may be bonded to the base material by the addition of an adhesive substance, such as polyurethane glue, spray adhesive or hot glue, or by an adhesive coating applied to the tape **110** such as a pressure sensitive adhesive.

(27) The tape **110** can be adhered to the base material **104** or the tape **110** can be adhered to the base material **110** and the fluid conduit **102**. For example, depending upon whether the fluid conduit **102** is thermoplastic, and the amount of heat energy applied to the tape **110**, the tape **110** can be adhered only to the base material **104**, in which case, the fluid conduit **102** is attached to the

base material **104** by being trapped between the tape **110** and the base material **104** but not necessarily being adhered to the fluid conduit **102**. Alternatively, the tape **110** can be adhered to the base material **104** and to the fluid conduit **102**. For example, if the tape **110** is coated with adhesive, the tape **110** can be adhered to the base material **104** and the fluid conduit **102**.

(28) As shown in FIG. **1**, the fluid conduits **102** are preferably positioned substantially parallel to each other and spaced across the width **106** of the base material. As is also shown in FIG. **1**, the spacing between the fluid conduits can be substantially uniform. However, the spacing of the conduits is preferably adjustable to suit various applications. For example, the conduits may be spaced closer together or farther apart. Additionally, the spacing can vary across the width of the base material; for example, for heating applications, the conduits **102** closer to the outside edges can be spaced more closely to compensate for heat loss near the edges, whereas, the conduits **102** positioned in the middle can be spaced more widely. Further, the fluid conduits **102** may be spaced to accommodate plant containers. For example, the fluid conduits **102** may be spaced so that plant containers may be placed between the conduits **102** so as to avoid the plant containers from crushing the fluid conduits **102**. Or, the fluid conduits **102** may be spaced so that plant containers may be placed directly on the conduits **102** so as to maximize heat transfer to the plant containers. In a further embodiment, suggested placements for plant containers (e.g., to achieve appropriate spacing between plants) may be printed directly on the mat (e.g., using the print head described herein).

(29) As shown in FIG. **1**, the conduits **102** can be coupled to an inlet manifold **112** and to an outlet manifold **114**. For example, alternating ones of the conduits **102** can, at one end of the conduits **102**, be coupled to the inlet manifold **112**, while the remaining conduits **102** can, at one end of the conduits **102**, be coupled to the outlet manifold **114**. As is also shown in FIG. **1**, at opposite ends, the conduits can be coupled to each other. More particularly, conduits **102** that are coupled to the inlet manifold **112** can be coupled to the conduits **102** that are coupled to the outlet manifold **114** by u-shaped “elbow” couplers **116**. It will be apparent that other arrangements are possible. For example, the elbow couplers **116** can be replaced with straight couplers which would allow further lengths of conduit to be connected to them (e.g., to splice mats together). As another example, the elbow couplers **116** can be replaced with T-couplers which would allow the ends of the conduits to be coupled to each other and to further lengths of conduit. The conduits **102** can be coupled to the inlet manifold **112**, to the outlet manifold **114** and to the “elbow” couplers **116** by, for example, compression fittings or clamps.

(30) As shown in FIG. **1**, fluid that enters the input manifold **112** can flow through the conduits **102** and then return to the outlet manifold **116**. Heated or cooled fluid can thus flow through the mat **100** so that the mat **100** functions as a heating or cooling device, respectively. In such an embodiment, the mat **100** can be part of a closed recirculating environmental control system **115** with the fluid being heated or cooled externally to the mat **100**, e.g., by a boiler or chiller, and cyclically returned to the mat **100**.

(31) In further embodiments, the conduits **102** may be used for one-way delivery of fluids, which can include gases. For example, in an irrigation system, the return manifold **116** can be omitted and the ends of the conduits **102** that would otherwise be connected to the return manifold **116** can be closed such that water or treated water instead exits the conduits **102** through perforations **117** or through irrigation fittings **119** located along the conduits **102**. Such irrigation fittings may include drip or spray irrigation fittings. Such irrigation water can be treated by infusing the water with CO₂ gas, in which case, the infused water can be, for example, delivered directly to plant leaves by foliar spraying via the conduits **102** present in the mat **100**.

(32) In still further embodiments, some of the conduits **102** attached to a mat **100** can carry one type of fluid while other conduits attached to the mat can carry another type of fluid. For example, some of the conduits **102** can be connected to each other to carry heating or cooling fluid as part of a closed heating or cooling system while other conduits **102** can be connected to each other to

deliver irrigation water or to deliver CO₂ gas. Such CO₂ gas could be generated by the same boiler that is also used to generate heated water which is delivered to the conduits **102** used for heating.

(33) FIG. **3** illustrates an example of such a mat. As shown in FIG. **3**, the conduits **102** can be coupled to a first inlet manifold **112**, to an outlet manifold **114** or to a second inlet manifold **118**. For example, selected ones of the conduits **102** can, at one end of the conduits **102**, be coupled to the first inlet manifold **112**, while other conduits **102** can, at one end of the conduits **102**, be coupled to the outlet manifold **114**. As is also shown in FIG. **3**, at opposite ends, these conduits can be coupled to each other by u-shaped “elbow” couplers **116**. The conduits coupled to the manifolds **112** and **114** can be part of a closed heating or cooling system. Other ones of the conduits **102** can be coupled to the second inlet manifold **118**. These conduits can be capped at their opposite ends by caps **120** and can include, for example, irrigation tubing (which may be perforated and/or capable of accepting irrigation fittings, e.g., barbed fittings), or gas tubing (which may or may not be gas-permeable). It will be apparent that other arrangements of conduit connections, caps, manifolds and tubing types are possible.

(34) FIG. **4** illustrates an apparatus **200** for the manufacture of a mat **100** with fluid conduit **102** in accordance with an embodiment of the present invention. As shown in FIG. **4**, the apparatus **200** comprises a stationary beam **202** and a movable shuttle assembly **204**. For this purpose, the beam **202** can be fitted with an internal or external linear track or bearing surface, while the shuttle **204** can be fitted with wheels or bearings that are movable along the track. The direction of movement of the shuttle **204** is left and right in the plane of the figure, as shown by arrows **206**.

(35) The apparatus **200** of FIG. **2** has a substantially flat elongated plate **208** against which the base material **104** and conduits **102** are positioned. The plate **208** is preferably in a fixed position such that the shuttle **204** moves in relation to the plate **208**. For example, the plate **208** can be fixed in relation to the beam **202**. The plate **208** is preferably at least as long as the base material **104** is wide. However, the width of the plate **208** need only be as wide at the width of the bonding tape **110**. For example, the plate **208** may be approximately twelve feet in length to accommodate base material **104** widths of up to twelve feet. However, the plate need only be approximately two to three inches wide to accommodate bonding tape widths of between two and three inches. It will be apparent that these dimensions are exemplary and that other dimensions are possible.

(36) The base material **104** and conduits **102** are shown in cross section in FIG. **4**, similar to FIG. **2**. A reel **210** of bonding tape **110** is mounted to the shuttle **204**. In operation, a roller **212**, which is also mounted to the shuttle **204**, presses the tape **110** against the conduits **102** and the base material **104**, such that the tape **110**, conduits **102** and base material **104** are all pressed together between the roller **212** and the plate **208**. The conduits **102**, being flexible, can be temporarily deformed or flattened during this process though the conduits **102** may substantially return to their original shape once the roller **212** passes over them.

(37) A heating element **214** is mounted to the shuttle **204**. The heating element **214** receives compressed air at a regulated air pressure. The compressed air is heated by the heating element **214** and delivered to an interface between the bonding tape **110** and the base material **104** by an air nozzle **216**. As the shuttle **204** moves across the mat **100** (from left to right as shown in FIG. **4**), heated air exits the nozzle **216** thereby heating the tape **110** and base material **104** just prior to their being pressed together by the roller **212**. The amount of heat energy delivered to the interface is adjustable and is dependent upon the air temperature delivered to the heating element **214** and the speed at which the shuttle **204** moves across the mat **100**. This heat energy is preferably adjusted so that the tape **110** is firmly bonded to the base material **104** due to thermoplasticity of the tape **110** and possibly also due to thermoplasticity of the base material **104**.

(38) The roller **212** is preferably formed of a heat-resistant elastic material. The roller **212** can be mounted on a lever arm **218** that is mounted to the shuttle **204**. The pressure exerted by the roller **212** against the tape **110**, conduits **102** and base material **104** is preferably adjustable and controlled

by a rod **220** which can be mechanically or hydraulically actuated. Clamps **222** can be provided to secure the base material **104** from movement during the process of heating and adhering the tape **110** to the base material **104**.

(39) Once the shuttle **204** reaches the edge of the base material **104** as it moves from left to right, the air nozzle **216** preferably moves out of the way of the tape **110** and the rod **220** retracts so as to lift the roller **220** away from the mat assembly **100**. Then, while the shuttle **204** continues to travel from left to right, a suction cup lifter **224** can be actuated to move downward and grab the tape **110** by suction and to lift the tape **110** clear of the mat assembly **100** while a cutter **225** (e.g., a motorized rotary fabric cutter) can be actuated to cut the tape **110**. The cutter **225** preferably cuts the tape approximately even with the right-most edge of the material **100** or slightly longer to provide sufficient extra tape to be later trimmed flush with the edge of the material **100**. The clamps **222** can then be released. Once the tape is cut, the shuttle **204** can be returned to its left-most position and the base material **104** and conduits **102** can be incrementally advanced (out of, or orthogonally to, the plane of FIG. 3) across the plate **208**. The increment by which the material is advanced determines the distance between rows of tape and is preferably adjustable. For example, the desired increment may be input by the equipment operator. The clamps **222** can then be actuated once again to secure the base material **104**. This positions the shuttle **204** and the materials to begin a next pass of the shuttle **204** and the process of adhering a next length of tape **110** to the base material **104**.

(40) The suction cup lifter **224** can include one, two or more suction cups. In an embodiment, suction is created by a vacuum air compressor which is configured to generate suction at the appropriate time in the cycle described above (i.e. prior to cutting the tape) and to release suction at an appropriate time in the cycle (i.e. after the tape is cut). In an embodiment, the suction cups of the suction cup lifter **224** can include air bleeds or vents to modulate the amount of vacuum generated.

(41) The functioning of the apparatus **200** is preferably mechanized such that the various mechanical operations, including advancing the material and conduits, clamping the material, passing the shuttle over the material to adhere the tape and conduits, as well as the suction cup lifting and cutting of the tape, releasing the clamps and returning the shuttle into position for a next pass are all performed automatically without human intervention. In this way, the apparatus can manufacture the finished mat **100** with little human intervention. Human intervention is expected to be needed to initially load the apparatus **200** with material, configure adjustable parameters, activate the apparatus **200** and remove finished material.

(42) As shown and described in connection with FIG. 4, the bonding tape **110** is bonded to the base material **104** as the shuttle **204** moves from left to right. It will be apparent that the apparatus can be configured such that the bonding tape **110** is bonded to the base material **104** as the shuttle **204** moves from right to left. For example, such an apparatus could appear as a mirror image to that shown in FIG. 4.

(43) FIG. 4 additionally illustrates a display screen **224**, which can be used to display information about operation of the apparatus **200** and to accept operator input (e.g., via touch screen input or other user interface). Such inputs can include, for example, adjusting the spacing between rows of tape, a heat setting for the heating element **214**, downward pressure of the roller **212**, air pressure at the nozzle **216**, speed of the shuttle **204**, and configuring print head **602** (FIG. 7), including selecting text to be printed.

(44) FIG. 5 illustrates a side view of an apparatus **400** for feeding of material for the manufacture of the mat assembly **100** in accordance with an embodiment of the present invention. The apparatus **400** of FIG. 5 can be used on conjunction with the apparatus **200** of FIG. 4. FIG. 6 illustrates a top view of the apparatus **400** of FIG. 5 in accordance with an embodiment of the present invention. FIGS. 4, 5 and 6 illustrate front, side and top views, respectively, which views are 90 degrees apart from each other.

(45) As shown in FIGS. 5 and 6, a plurality of spools **402**, each holding conduit **102** (e.g., conduit

for fluids or gas), are positioned to feed the conduit **102** towards the apparatus **200** shown in FIG. **4**. FIG. **5** shows a side view of the plate **208** of FIG. **4** (upon which the heated tape **110**, conduit **102** and base material **104** are pressed together) while FIG. **6** shows a top view of the plate **208**; however, for clarity of illustration, some details, including the beam **202** and shuttle assembly **204**, are omitted from FIGS. **5** and **6**.

(46) As is also shown in FIGS. **5** and **6**, each conduit **102** can pass through a corresponding eyelet **404** and guide tube **406** before reaching the plate **208**. FIG. **5** also shows a roll **408** of base material **104** which, when unrolled, passes over a roller or guide **410** prior to reaching the plate **208**. Arrows show the direction of material movement in FIG. **5**. Once the materials pass over the plate **208** and are bonded together, the completed mat assembly **100** then passes over rollers or guides **412** and is spooled in a completed roll **414** of mat assembly **100**. This roll **414** can then be removed from the apparatus **400**. FIG. **5** also shows spools **416** which can be used for storage of conduit **102** prior to assembly into mat assemblies **100**.

(47) The eyelets **404** can each include a round opening through which the conduit passes. The eyelets **404** can include roller guides in order to reduce friction.

(48) FIG. **6** shows the spools **402**, roll **414**, eyelets **404**, roll **408**, guide tubes **406**, plate **208** and guides **412**. For clarity of illustration, the conduits **102**, base material **104** and other features are omitted from FIG. **6**. FIG. **6** shows spacing of the guide tubes **406** which controls the spacing of the conduits **102** in the finished material **100**. In an embodiment, the guide tubes **406** (and possibly also the eyelets **404**) are mounted such that the spacing between them can be adjusted by an operator of the apparatus. Additionally, in some configurations, not all of the guide tubes **406** will be required and, thus, unused guide tubes **406** can preferably be moved out of the way.

(49) FIG. **7** illustrates an apparatus for the manufacture of a mat with fluid conduit including an print head, weld tape meter and cooling air jet in accordance with an embodiment of the present invention. FIG. **7** is similar to FIG. **4**, except that FIG. **7** additionally illustrates a print head **602** and guide **604** that are coupled to the shuttle **204**. This permits printing to be applied to the tape **110** prior to adhering the tape **110** to the base material **104**. The tape **110** can be printed with a brand name or logo, identifying information (e.g., to identify a product type, application or product number), instructional information, barcode, or any other type of information.

(50) FIG. **7** additionally illustrates a proximity sensor **606** that is configured to detect the size of the tape roll **210** by sensing the distance between the sensor **606** and the surface of the tape **210**. As the tape roll **210** is consumed, this distance becomes larger which is detected by the sensor **606**. In an embodiment, once the roll **210** reaches a predetermined reduced size, the sensor **606** triggers an audible and/or visual alarm which alerts the operator of the need to replace the tape roll **210**. In an embodiment, the sensor **606** can be configured to halt operation of the apparatus as well.

(51) FIG. **7** additionally illustrates an air cooling nozzle **608** which is configured to direct cooling air at the roller **212**. This delivery of cooling air prevents the surface temperature of the roller **212** from becoming excessive (due to the heated air from nozzle **216**) which could cause undesirable adherence of the tape **110** to the roller **212**.

(52) FIG. **8** illustrates a side view of an apparatus for feeding of material in connection with the manufacture of a mat with fluid conduit having conduit rollers in accordance with an embodiment of the present invention. FIG. **8** is similar to FIG. **5**, except that FIG. **8** additionally illustrates a pair of guide rollers **418** and **420**. The guide rollers **418** and **420** can extend the width of the apparatus (similar to rollers **412** shown in FIG. **6**) and are positioned near the guide tubes **406**. Conduit **102** passes between the guide rollers **418** and **420** before passing through the guide tubes **406**. The rollers **418** and **420** function to align the conduit **102** with the guide tubes **406** so as to reduce friction between the conduit **102** and the guide tubes **406**.

(53) FIG. **9** illustrates a perspective view of an apparatus for the manufacture of a mat with fluid conduit in accordance with an embodiment of the present invention. For reference, FIG. **9** shows the beam **202**, shuttle **204** and plate **208** described herein, however, some details of the apparatus

shown in FIGS. 4-8 are omitted from FIG. 9 for clarity of illustration. FIG. 9 shows that the rollers **412** of FIGS. 5 and 8 can be replaced with a cylindrical load spreader **610**. As shown in FIG. 9, finished material **100** to which the conduits have been attached passes over the load spreader **610** before being spooled into the completed roll **414** (FIGS. 5 and 8) of mat assembly **100**. Cutters **612** may be provided to trim the ends of the tape **110** and/or the edges of the finished material **100**. The cutters **612** are preferably movable from side to side to adjust to accommodate a desired width of the finished material **100**.

(54) FIG. 10 illustrates a perspective view of an apparatus for the manufacture of a mat with fluid conduit in accordance with an alternative embodiment of the present invention. The embodiment shown in FIG. 10 is similar to the embodiments shown and described herein in connection with FIGS. 4-9, except that the movable shuttle **204** is replaced by a heat sealing bar **502**. The heat sealing bar **502** can include a heating element so that the entire bar **502** may be heated or so that a portion of the bar **502** may be heated. For example, an electrical heating wire can be contained within the bar **502**. Such a heating wire may be in contact with the bar **502** so as to heat the bar **502** itself or the electrical heating wire may be isolated from the bar **502** (e.g., by a heat insulator such as silicone rubber) so that the electrical heating wire can impart heat energy directly to the thermoplastic bonding tape **110**.

(55) The apparatus of FIG. 10 can be used in conjunction with one or more of the apparatuses shown in FIGS. 5, 6, 8 and 9. Accordingly, the heat sealing bar **502** of FIG. 10 may be used to press the thermoplastic bonding tape **110** (e.g., FIG. 2) against the fluid conduits **102** (e.g., FIG. 2) and base layer **104** (e.g., FIG. 2) by trapping them between the sealing bar **502** and the plate **208** of FIGS. 5, 6, and 9. Also shown in FIG. 10 are pressure applicators **504** which may be, for example, electric motor driven or hydraulically actuated. The pressure applicators **504** function to move the bar **502** up and down and apply pressure to the bar **502** thereby pressing the bar **502** against the plate **208**. In an embodiment, the plate **208** may be heated in order to aid in welding the tape to the base layer **104**.

(56) Also shown in FIG. 10 is the tape **110**, tape roll **210** and a roll holder **506** for the tape roll **210**. While not shown in FIG. 10 for clarity of illustration, it will be understood that elements of the apparatus shown in any of the figures herein may be incorporated into the apparatus of FIG. 10. This includes, but is not limited to, the plate **208**, guide tubes **406**, guide rollers **418** and **420**, cylindrical load spreader **610**, cutter **225**, sensor **606** and cutters **612**.

(57) In the embodiment of FIG. 10, the tape **110** is unrolled from the roll **210** and positioned across the conduit **102** and base layer **104**. The sealer bar **502** is then lowered onto the tape **110**, conduit **102** and base layer **104**. This may result in temporarily deforming the conduit **102**. Heat is therefore applied to the tape **110** after the tape is positioned across the conduit **102** and base layer **104**. Once the tape **110** is pressed onto and adhered to the base layer **104**, the tape **110** may be cut and the finished material **100** may be advanced as described herein. Then, a next strip of tape **110** may be unrolled and positioned across the conduit **102** and base layer **104**. The above-described steps may then be repeated.

(58) FIG. 11 illustrates a perspective view of a pneumatic brake assembly and finished material roll motion controller assembly in accordance with an embodiment of the present invention. FIG. 11 shows a shaft **612** upon which the roll **408** of base material **104** (FIGS. 5 and 8) is rolled. The shaft **612** is coupled to a pneumatic brake assembly **614** which applies braking force to the shaft **612** in order to maintain tension in the base material **104** as it is passed through the apparatus of FIGS. 4-9. Also shown in FIG. 11 is control housing **616** to which a control knob **618** and air pressure gauge **620** are mounted. The control knob **618** can be used to adjust the air pressure applied to the pneumatic brake assembly **614** and thereby control the braking force applied to the shaft **612**. The pressure gauge **618** can be used to monitor the air pressure applied for pneumatic braking.

(59) Also shown in FIG. 11 is the roll **414** of finished mat **100**. The roll **414** can be mounted to a shaft **622** which is driven by a motor **624** and gear box **626**. Turning of the shaft **622** draws

material through the apparatus of FIGS. 4-9. The motor 624 is preferably controlled by control electronics such that the roll 414 is incrementally turned as the material is processed by the apparatus of FIGS. 4-9 and so as to maintain tension in the material against the pneumatic brake assembly 614. A proximity sensor 628 is configured to detect the size of the roll 414 by sensing the distance between the sensor 628 and the surface of the roll 414. The distance, as sensed by the proximity sensor 628, is used by the control electronics to control rotation of the shaft 622. This sensed distance information is useful because, as the roll 414 diameter increases, the shaft 622 needs to rotate by a lesser amount in order to draw the same length of material onto the roll 414. As explained herein, the finished material 100 is fed through the machine in increments that correspond to a desired distance between rows of tape. This increment can be controlled by turning the shaft 622 by an appropriate amount between the application of each row of bonding tape 110. However, in order to maintain uniform spacing between rows of tape, the shaft 622 will need to turn by different numbers of degrees (radians) dependent upon the outer diameter of the roll 414. To summarize, the sensor 628 determines the current size of the roll 414 which information is used to determine how much to rotate the shaft 622 to maintain uniform tape spacing. Electronics for controlling the motor 624 and configured to receive a signal from the sensor 628 can be contained in the housing 616. A user interface 630 at the housing 616 can include appropriate user controls (e.g. ON/OFF switches, emergency shut-off, etc.)

(60) The foregoing detailed description of the present invention is provided for the purposes of illustration and is not intended to be exhaustive or to limit the invention to the embodiments disclosed. Accordingly, the scope of the present invention is defined by the appended claims.

Claims

1. A flexible mat with fluid conduit, comprising: a flexible base layer; a plurality of fluid conduits arranged substantially in parallel to each other and adjacent to the base layer; and a plurality of long and narrow strips of tape arranged substantially in parallel to each other and substantially orthogonal to the fluid conduits, the fluid conduits being positioned between the base layer and the strips of tape, and the strips of tape being thermoplastically welded to the base layer, thereby trapping the fluid conduits between the strips of tape and the base layer.
 2. The flexible mat with fluid conduit according to claim 1, wherein one or more of the plurality of fluid conduits are configured to carry heat transfer fluid.
 3. The flexible mat with fluid conduit according to claim 2, wherein the one or more of the plurality of fluid conduits configured to carry heat transfer fluid form part of a closed recirculating environmental control system.
 4. The flexible mat with fluid conduit according to claim 1, wherein one or more of the plurality of fluid conduits are configured to carry irrigation water.
 5. The flexible mat with fluid conduit according to claim 4, wherein the one or more of the plurality of fluid conduits configured to carry irrigation water comprise perforations or are configured to accept irrigation fittings.
 6. The flexible mat with fluid conduit according to claim 1, wherein one or more of the plurality of fluid conduits are configured to carry gas.
 7. The flexible mat with fluid conduit according to claim 1, wherein the plurality of fluid conduits are configured to carry two or more fluids selected from the group consisting of: heat transfer fluid, irrigation water, and gas.
 8. The flexible mat with fluid conduit according to claim 1, wherein the base layer is thermoplastic.
 9. The flexible mat with fluid conduit according to claim 1, the strips of tape being flexible.
 10. The flexible mat with fluid conduit according to claim 1, the strips of tape comprising thermoplastic bonding tape.
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