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(54) SYSTEM FOR ARTIFICIAL TURF MANUFACTURING

(57) The invention relates to a system (100) for manufacturing an artificial turf (136), including:
- a dielectric barrier discharge device (112) including a first electrode (402, 602, 604, 958) and a second electrode (404);
- a conveyor unit (108, 110, 107) configured for moving a carrier mesh (960) through an air gap (405) formed between the first electrode and the second electrode, wherein the carrier mesh includes a backside, and wherein the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside;
- a control unit (114) configured to control the dielectric barrier discharge device to apply a dielectric barrier discharge to the backside of the carrier mesh as the carrier mesh moves through the air gap for plasma-activating the backside; and
- a dispensing unit (116) configured to apply a backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

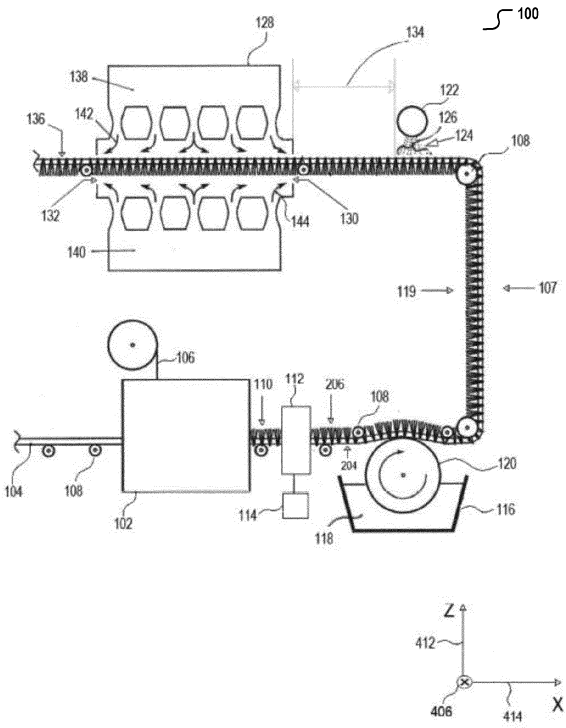

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] Certain embodiments of the invention relate to the field of artificial turfs. More specifically, certain embodiments of the invention relate to systems and devices for manufacturing an artificial turf and artificial turf products.

BACKGROUND OF THE INVENTION

[0002] Artificial turf or artificial grass is surface that is made up of fibers which is used to replace grass. The structure of the artificial turf is designed such that the artificial turf has an appearance which resembles grass. Typically, artificial turf is used as a surface for sports such as soccer, American football, rugby, tennis, golf, for playing fields, or for exercise fields. Furthermore, artificial turf is frequently used for landscaping applications.

[0003] An advantage of using artificial turf is that it eliminates the need to care for a grass playing or landscaping surface, such as regular mowing, scarifying, fertilizing and watering. Watering can be difficult due to regional restrictions for water usage. In some climatic zones, regrowing grass for forming a closed grass cover is slow compared to the damage incurred by natural grass surfaces from playing and/or exercising on the field. Artificial turf fields, though they do not require similar attention and effort to be maintained, have lifetimes that are limited in part by the wear-and tear of normal use, and in part by the effects of cyclic seasonal changes (e.g., heat, moisture, freeze/thaw, air-born pollutants, etc.). For example, artificial turfs typically exhibit at least some type of wear after about 5-15 years. Mechanical damage from use and exposure to UV radiation, thermal cycling, interactions with chemicals and various environmental conditions may generate significant wear on artificial turf.

[0004] It is therefore beneficial to provide a system for the manufacture of artificial turf which provides artificial turf that can better tolerate the constant stresses imposed from use and exposure to the elements, and which can increase the useful lifespan of an artificial turf.

[0005] US 7,026, 031 B2 (Holeschovsky et al.), published April 11, 2006, discloses a corona discharge process. Corona discharge processes use, as is conventionally known, only one electrode, whereby the electrode is not surrounded by a dielectric.

BRIEF SUMMARY OF THE INVENTION

[0006] The invention relates to a system for manufacturing an artificial turf, as described by the subject matter of the independent claim. Advantageous embodiments are described in the dependent claims. Embodiments of the present invention can be freely combined with each other if they are not mutually exclusive.

[0007] In one aspect, the invention relates to a system for manufacturing an artificial turf, comprising:

- a dielectric barrier discharge device including a first electrode and a second electrode;
- a conveyor unit configured for moving a carrier mesh through an air gap formed between the first electrode and the second electrode, wherein the carrier mesh includes a backside, and wherein the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside;
- a control unit configured to control the dielectric barrier discharge device to apply a dielectric barrier discharge to the backside of the carrier mesh as the carrier mesh moves through the air gap for plasma-activating the backside; and
- a dispensing unit configured to apply a backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

[0008] According to some embodiments, the first and second electrodes are elongated in a first direction, and the conveyor unit is configured to move the carrier mesh in a second direction that is perpendicular to the first direction.

[0009] According to some embodiments, the carrier mesh includes a frontside, wherein the first electrode is adjacent to the backside, wherein the second electrode is adjacent to the frontside.

[0010] According to some embodiments, the second electrode is at least partially encased in a dielectric, the dielectric extending at least in a direction towards the first electrode.

[0011] According to some embodiments, the second electrode is shaped as a solid or hollow cylinder, wherein in particular the dielectric and the carrier mesh are positioned such that the dielectric is in contact with the frontside of the carrier mesh.

[0012] According to some embodiments, the dielectric comprises a plastic material.

[0013] According to some embodiments, the dielectric has a thickness of at least 0.2 cm, in particular a thickness of 0.2 cm to 10.0 cm, in particular of 1 cm to 5 cm, preferably 2.0 cm to 3.0 cm.

[0014] According to some embodiments, the dielectric is plastic or rubber, in particular hard rubber.

[0015] According to some embodiments, the dielectric has a dielectric constant of at least 2.0, preferably higher, e.g., at least 2.2, or at least 2.5, or at least 3.0.

[0016] According to some embodiments, the second electrode is configured to be rotatable about a longitudinal axis.

[0017] According to some embodiments, the system comprises a motor configured to move the carrier mesh through the air gap formed between the first electrode and the second electrode at least in part by rotating the second electrode with the dielectric.

[0018] According to some embodiments, the system comprises a user interface enabling a user to manually adjust the speed of the carrier mesh moving through the air gap. In addition, or alternatively, the control unit is

configured to automatically adjust the speed.

[0019] For example, the speed may be adapted in dependence on the chemical composition of the backing, e.g., the curing speed, and/or in dependence of the speed of other machines in the manufacturing facility such as the dispensing unit or tufting unit or the ovens for drying the backing. In addition, or alternatively, the speed may be adapted to achieve a desired total amount of energy of applied plasma activation per area of the carrier mesh. The user interface can be, for example, a mechanical interface such as a knob or a digital interface such as a touch-screen, mouse, keyboard and the like.

[0020] According to some embodiments, the control unit is configured to control the application of the dielectric barrier discharge to the backside of the carrier mesh at an energy density of between 0.5 J cm^2 and 0.6 J/cm^2.

[0021] According to some embodiments,

- the system further comprises a user interface for manually adjusting a gap between the first electrode and the backside of the carrier mesh and/or
- the control unit is configured to automatically adjust the gap between the first electrode and the second electrode.

For example, the gap (measured from the surface of the dielectric enchasing the second electrode to the surface of the first electrode facing towards the second electrode) may be smaller than 80 mm, e.g. smaller than 50 mm, e.g. smaller than 45 mm.

[0022] The user interface for adapting the distance can be, for example, a mechanical interface such as a knob, a lever or a crank, or a digital interface such as a touch-screen, mouse, keyboard and the like.

[0023] According to embodiments, the first electrode and the carrier mesh are positioned such (e.g. as a result of an adjustment of the gap or in accordance with the original device architecture) that a distance between the first electrode and the surface of the backside of the carrier mesh and the fiber portions comprised therein is smaller than 10 mm, in particular smaller than 5 mm, in particular between 0 mm and 3 mm.

[0024] According to some embodiments, the control unit is configured to control the dielectric barrier discharge device to continuously apply the dielectric barrier discharge to the backside for plasma-activating the backside.

[0025] According to some embodiments, the first electrode is a single wire or a set of two or more wires.

[0026] According to some embodiments, the first electrode is a conductive profile or a set of two or more conductive profiles. For example, a conductive profile can be a metal rod or metal bar or a profile having an L-shaped or T-shaped cross section.

[0027] According to some embodiments, the first electrode is a set of two or more first electrodes (e.g., two or more wires or two or more profiles) galvanically decoupled from each other.

[0028] According to some embodiments, the control unit is configured to control the dielectric barrier discharge device to apply the dielectric barrier discharge (for plasma-activating the backside of the carrier mesh and at least some of the fiber portions protruding therefrom) by enabling the formation of covalent bonds between the backside (backside surface of the carrier mesh and at least some of the fiber portions protruding therefrom) and the applied backing layer for providing increased binding between the fibers and the applied backing layer.

[0029] According to some embodiments, the backside of the carrier mesh forms a non-planar surface. For example, the backside of the carrier mesh may comprise tuft rows protruding from the backside of the carrier mesh, thereby exposing at least some portions of at least some of the fibers to the dielectric plasma discharge device.

[0030] According to some embodiments, the system for manufacturing the artificial turf comprises the carrier mesh, whereby the carrier mesh is an artificial turf carrier mesh and the fibers integrated therein are artificial turf fibers.

[0031] According to embodiments, the system further comprises a fiber inserter configured to receive the artificial turf carrier mesh and artificial turf fiber, and to insert the artificial turf fiber into the carrier mesh.

[0032] According to embodiments, the system for manufacturing the artificial turf is an inline manufacturing facility for artificial turf.

[0033] According to embodiments, the fiber inserter (if present), the conveyor unit, the dielectric barrier discharge device and the dispensing unit are elements of the same manufacturing assembly line and are operatively coupled to each other.

[0034] For example, the operative coupling is implemented such that the carrier mesh comprising the inserted fibers is transported by the conveyor unit from the fiber inserter to the dielectric barrier discharge device for performing a plasma activation of the backside of the carrier mesh and at least some fiber portions of the inserted fibers protruding from the backside, and then transported to the dispensing unit configured to apply the backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

[0035] This may have the advantage that the fibers, which may be coupled only loosely to the carrier mesh after their insertion, are strongly integrated in the carrier mesh by performing the plasma activation step and by applying the backing on the plasma-activated backside of the carrier mesh and at least some of the fiber portions protruding therefrom. Hence, the artificial turf output by the inline manufacturing facility and/or by the above-mentioned manufacturing assembly line already comprises fibers which are firmly integrated and will not be lost during later post-processing steps. It is also ensured that no fibers are lost by transporting a carrier mesh with only loosely integrated fibers to a different manufacturing line or a different manufacturing facility.

[0036] According to embodiments, the system comprises the artificial turf and/or the carrier mesh and the fibers integrated therein.

[0037] In yet another aspect, disclosed herein is a further system configured for manufacturing an artificial turf. The system is configured to move a carrier through an air gap formed between a first electrode and a second electrode of a dielectric barrier discharge device. The system comprises a dielectric barrier discharge device configured to apply a dielectric barrier discharge to one side of the carrier for plasma-activating the side. The system is configured to use the plasma-activated carrier for manufacturing the artificial turf.

[0038] For example, the carrier can be a carrier mesh or a carrier foil. The plasma-activated side may be a backside of the carrier (opposed to the side from which the longer parts of the artificial turf fibers will protrude once the fibers have been integrated). According to some examples, the use of the plasma-activated carrier for manufacturing the artificial turf comprises integrating artificial turf fibers into the plasma-activated carrier, e.g., by means of tufting, weaving, knitting or other types of fiber insertion techniques, and then applying the backing. The dielectric barrier discharge may be applied as described for the other embodiments and examples described herein.

[0039] In a further aspect, the invention relates to a manufacturing facility for artificial turf.

[0040] In a further aspect, described herein is a corresponding method for manufacturing an artificial turf and an artificial turf obtainable according to the method. Features described herein with respect to the manufacturing method are, according to embodiments, embodied or implemented in the system for manufacturing artificial turf. Likewise, features described herein with respect to the system of manufacturing the artificial turf are, according to embodiments, embodied or implemented in the method of manufacturing the artificial turf. Advantageous effects of features of the manufacturing method are likewise observable for the respective, analogous features of the manufacturing system.

[0041] In a further aspect, a method of manufacturing an artificial turf is described herein. The method includes moving a carrier mesh through an air gap formed between a first electrode and a second electrode of a dielectric barrier discharge device, where the carrier mesh includes a backside, and where the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside, applying a dielectric barrier discharge to the backside of the carrier mesh for plasma-activating the backside, and applying a backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

[0042] For example, applying a dielectric barrier discharge to the backside of the carrier mesh for plasma-activating the backside may comprise applying the dielectric barrier discharge to the backside of the carrier mesh and to the portions of at least some of the fibers protruding to the backside of the carrier mesh (and forming, for example, tuft bundles or tuft rows).

[0043] Advantageously, applying a dielectric barrier discharge to the backside of the carrier mesh for plasma-activating the backside, and then applying a backing layer to the plasma-activated backside of the carrier mesh, provides an artificial turf having improved binding between the backside of the mesh and the backing layer, and moreover, improved binding between the fibers integrated into the mesh and the backing layer, in comparison to the binding between backing layer and fibers integrated into a mesh whose backside is not plasma-activated. The binding forces between the fibers, which are often made of an apolar polyolefin such as polyethylene, and the - typically polar - backing which can be made, e.g., from polyurethane, is often weak. By applying the dielectric barrier discharge to the backside of the carrier mesh and on fiber portions protruding to the backside will significantly increase the strength with which the fibers are integrated into the carrier mesh.

[0044] In one embodiment, the first and second electrodes are elongated in a first direction, and the carrier mesh is moved in a second direction that is perpendicular to the first direction.

[0045] In another embodiment, the above-mentioned method is used for increasing the tuft bind and/or for increasing the homogeneity of tuft bind distribution in an artificial turf. The tuft bind and its distribution may be measured via the homogeneity of tuft withdrawal force.

[0046] In another embodiment, the carrier mesh includes a frontside. The first electrode is adjacent to the backside, the second electrode is adjacent to the frontside. For example, the front side may be the side from which the parts of the fibers that form the turf will protrude in basically upright direction once the artificial turf is installed at the use site and the backside may be the side where the backing is to be applied. Some portions of the fibers protrude to the backside of the carrier mesh, e.g., fiber portions comprised in tuft bundles and tuft rows, but the fiber portions exposed to the backside of the carrier mesh are shorter than the fiber portions protruding from the frontside and forming the turf.

[0047] The dielectric barrier discharge device comprises a dielectric. In particular, the second electrode of the dielectric barrier discharge device is at least partially enchased in the dielectric. Typically, the dielectric constant of the dielectric of the dielectric barrier discharge device is higher than the dielectric constant of the objects (greige good, carrier, etc.) transported through the gap for plasma-activation.

[0048] According to embodiments, the second electrode is at least partially encased in the dielectric. The dielectric extends at least in a direction towards the first electrode.

[0049] Advantageously, the application of the dielectric barrier discharge using a second electrode which is at least partially encased in a dielectric, and then applying a

backing layer to the plasma-activated backside of the carrier mesh, provides an artificial turf having even more improved binding between the backside of the mesh and the backing layer, and moreover, even more improved binding between the fibers integrated into the mesh and the backing layer, in comparison to the binding between the backing layer and fibers integrated into a mesh whose backside is not plasma-activated.

[0050] In contrast to a corona discharge system, typically having only a single electrode, the dielectric barrier discharge (DBD) device of the present invention has at least two electrodes, at least one of which is at least encased in (i.e., at least partially surrounded by) a dielectric. In case a corona discharge system uses two electrodes, the counter electrode is geometrically highly asymmetric with respect to the cathode and no dielectric barrier is used. The dielectric used in a dielectric barrier discharge device advantageously limits current flow and distributes the plasma discharge more uniformly over the backside of the carrier mesh, thereby enabling the formation of a more homogeneous distribution of covalent binding between the backside and the applied backing layer, resulting in an overall improvement in the strength of attachment between the backing layer and the fibers of the carrier mesh. In effect, the dielectric enables the plasma discharge (i.e., the bombardment of the mesh backside (surface) by high energy ions from the plasma formed in the air gap) to be more homogeneously distributed onto the mesh backside, thereby resulting in the formation of a more homogeneous distribution of covalent bonds with the backing layer, which is applied shortly thereafter to the backside is plasma-activated. This is particularly advantageous in the context of products having an uneven surface to be treated, such as the uneven backside surface of greige goods comprising tuft rows. Without the wish to be bound by any theory, applicant believes that the insulating properties of the tuft rows, and hence the irregularities they cause in the electric field in the air gap, are comparatively small compared to the impact of the dielectric surrounding the second electrode. Hence, the dielectric ensures that a homogeneous plasma-discharge can be achieved also on uneven surfaces such as the backside of greige good.

[0051] In a further advantageous aspect, much less energy is consumed than in other existing plasma activation approaches. Applicant has tested plasma jet nozzles and has observed that much more energy is needed for achieving a similar improvement of the tuft bind as with the DBD machine. Furthermore, the excess heat generated by the plasma jet nozzles result in a head-degradation of the polymer material of the carrier mesh. This problem can be avoided by using a DBD machine which generates much less heat and nevertheless achieves a significant improvement of tuft bind.

[0052] In another embodiment, the dielectric is composed of plastic material. In particular, the dielectric material may be a plastic that is hard and robust enough to be used to transport greige good in a production plant for artificial turf.

[0053] Preferably, the dielectric has a dielectric constant (relative permittivity) of at least 2.0, preferably higher, e.g., at least 2.2, or at least 2.5, or at least 3.0. In some examples, the dielectric has a dielectric constant between 2.0 and 6.0. In general, the higher the dielectric constant, the better a material functions as an insulator. For example, rubber has a very high dielectric constant, and so it may be used as the dielectric. For example, different types of rubber have dielectric constants between 2.0 and 4.0. According to one embodiment, rubber, in particular hard rubber, having a dielectric constant of about 2.8, may be used. Other types of material may also be used, e.g., nylon having a dielectric constant of 3.4 to more than 22.

[0054] In some embodiments, the thickness of the dielectric material covering/embedding the second electrode is at least 0.2 cm. For example, the thickness can be 0.2 cm to 10.0 cm, in particular 1 cm to 5 cm, preferably 2.0 cm to 3.0 cm.

[0055] In yet another embodiment, the second electrode is shaped as a cylinder with a circular or ellipsoid cross-section, coated with the dielectric material. The cylinder can be, for example, a hollow or solid cylinder. The second electrode may be a metal cylinder. The cylinder formed by the second electrode and the dielectric material coating the cylinder walls of the second electrode can be mounted rotatably in the plasma-activation machine.

[0056] In some embodiments, the dielectric is in contact with the frontside of the carrier mesh, e.g., for transporting the carrier mesh with the fibers (the greige good) by a rotational movement of the second electrode with the dielectric material layer. The dielectric may be a hollow cylinder surrounding the cylindrical metal core that serves as the second electrode. Advantageously, a dielectric shaped as a hollow cylinder and in contact with the frontside of the carrier mesh has less surface area in contact with the frontside of the carrier mesh as compared to dielectrics of other shapes, thereby minimizing a build-up of static electrical charges on the carrier mesh and/or on the dielectric due to the relative motion between them as the carrier mesh moves through the air gap.

[0057] In some embodiments, the second electrode being at least partially encased in the dielectric is configured to be rotatable about its longitudinal axis. According to some embodiments, the second electrode is coupled to a motor configured to rotate the second electrode and the dielectric along the longitudinal axis, thereby moving the carrier mesh through the air gap formed between the first electrode and the second electrode. According to other embodiments, the second electrode is not coupled to a motor and is rather passively rotated by frictional forces with the greige good when the carrier mesh is moved by other actuators through the air gap.

[0058] Advantageously, causing the second electrode encased in the dielectric (which is in contact with the

frontside of the carrier mesh) to rotate about its longitudinal axis essentially eliminates or reduces a build-up of static electrical charges on the carrier mesh and the dielectric, since there is no relative motion at the contact points between them as the carrier mesh moves through the air gap.

[0059] In one embodiment, applying the backing layer to the plasma-activated backside (and at least some of the fiber portions protruding to the backside, e.g., within tuft rows) includes applying the backing layer within a time period of less than two days, e.g. less than one day, e.g. less than 1 hour, e.g. less than 5 minutes after applying the dielectric barrier discharge to the backside of the carrier mesh. According to some embodiments, the artificial turf is manufactured in accordance with a roll-to-roll process and applying the backing layer to the plasma-activated backside includes performing the plasma activation step and performing the applying of the backing layer within the roll-to-roll process. "Roll-to-roll" means that a roll of greige good or a roll of carrier mesh is provided as input, which is unrolled, further processed (e.g. tufted (in the case of the carrier mesh), plasma-activated, subject to the application of the backing layer, heat-treated, and then rolled up to provide a roll of the product, i.e., artificial turf.

[0060] Advantageously, applying the backing layer within a predefined time period after applying the dielectric barrier discharge to the backside of the carrier mesh results in most, if not all, of the number of plasma-enhanced receptive sites created by the plasma discharge being still available for forming respective covalent bonds with the backing layer, when applied.

[0061] In one embodiment, the dielectric barrier discharge and the backing layer are applied as subsequent steps in a production line system.

[0062] Advantageously, applying processing steps in a production line system, such as in system of Fig. 1, or in a separate system that only includes the processing steps of applying the dielectric barrier discharge and applying the backing layer, reduces the cost and time for manufacturing an artificial turf, provides for a more efficient process, and simplifies the customization of new production line systems that may include any combination of the processing steps disclosed in the system embodiment of Fig. 1.

[0063] In other embodiments, the carrier mesh is moved through the air gap at a manually-adjustable and/or automatically-adjustable speed.

[0064] Advantageously, providing a manually-adjustable and/or automatically-adjustable speed results in a more efficient matching of the speed with other parameters of the system, such as rate of application of the backing layer mixture from the dispensing unit and/or power applied to the backside of the carrier mesh as a plasma discharge from the DBD device, for optimizing the number of covalent bonds between the backside of the carrier mesh and the backing layer.

[0065] According to embodiments, the second electrode is the anode and the first electrode is the cathode.

[0066] According to some embodiments, the first electrode is a single wire or a set of two or more wires. In case multiple wires are used, all wires preferably have approximately the same distance to the surface of the dielectric. Using multiple wires may have the advantage that the plasma is applied more homogeneously over a larger surface.

[0067] According to other embodiments, the first electrode is a conductive profile, e.g. a metal profile, e.g., a rod or bar or a profile having an L-shaped or T-shaped cross section, or a set of two or more of said profiles. Advantageously, this may increase the mechanical rigidity and stability of the first electrode and may ensure that the air gap has basically the same width over multiple meters, the typical width of an artificial turf roll.

[0068] According to some examples, the multiple wires or multiple profiles constituting the first electrode are placed and configured such that they are oriented in parallel to each other and have basically the same distance to the surface of the carrier mesh.

[0069] This may have the advantage of providing a particular strong and efficient plasma-activation of the backside of the carrier mesh and of at least some of the fiber portions protruding therefrom: applicant has observed that the strength of plasma-activation does not increase linearly with the applied voltage or power. Rather, a saturation is reached (see the small increase of tuft bind resulting from increasing the power from 500 Watt to 700 Watt as illustrated in figure 9). However, by using two or more first electrodes, a significant increase of the tuft bind can be achieved: Two simultaneously discharging electrodes are equivalent to a double treatment of the surface, which increases the probability of maximum surface activation.

[0070] According to some examples, the multiple wires or multiple profiles are oriented in parallel and/or have the same cross-sectional shape.

[0071] According to some examples, the first electrode and the second electrodes are oriented in parallel to each other and have approximately (+/-10%) the same length.

[0072] According to some examples, the multiple wires, rods or bars constituting the first electrode are galvanically decoupled from each other. For example, the multiple wires, rods or bars constituting the first electrode may all be coupled to the same electrical energy source or may each be coupled to a respective electrical energy source. The electrical energy source or sources are configured for the generation of a high voltage.

[0073] The galvanically decoupling of the multiple electrodes forming the first electrode (also referred to as the "multiple first electrodes") may have the advantage that if one of these first electrodes discharges at least partially due to contact with a certain point of the surface of the carrier mesh, this does not lead to a significant discharge of the one or more other first electrode(s). In fact, the other first electrode(s) retains its (their) high voltage

potential unchanged, so that even in the case of a short-term partial discharge of one of the two or more first electrodes as a result of the one first electrode locally contacting the backside of the carrier mesh, the other one continues to perform the plasma activation. This has the advantage that a particularly homogeneously distributed, large-area plasma activation can be achieved also in very uneven surfaces such as the backside of a carrier mesh comprising tuft rows. In general, it is advantageous to position the first electrode or first electrodes as close as possible to the surface of the carrier mesh in order to generate a very high voltage field there. However, in some use-case scenarios, contact between the first electrode and the surface of the carrier mesh should be avoided, as this leads to unwanted, local plasma discharges, which is disadvantageous because the local discharge causes a reduction of the applied voltage field and plasma activation is reduced or even interrupted for a short time along the entire length of the affected first electrode. However, due to the uneven nature of the carrier mesh with the tuft rows, occasional punctiform contact cannot be completely prevented. By using one or more additional first electrodes that are galvanically decoupled from each other, it is possible to ensure that even in the event of a local discharge of one of the electrodes, the other first electrodes still maintain their voltage field and plasma activation can take place there.

[0074] According to some examples, the galvanic decoupling can be achieved by using a dielectric barrier discharge machine having a discrete architecture. For example, each of the multiple first electrodes may be connected to a respective power source, e.g., a primary power source or a capacitor. Hence, the dielectric plasma discharge device may comprise multiple power sources, whereby each power source serves only one of the first electrodes for ensuring that the voltage field generated between the respective one of the first electrodes and the second electrode is not affected by a complete or partial discharge of another one of the first electrodes.

[0075] According to other embodiments, the same power source is used for the multiple first electrodes.

[0076] According to embodiments, the dielectric barrier discharge device is configured to generate a voltage field between the one or more first electrodes on the one hand and the second electrode on the other hand of at least 1 kV, in particular of at least 10 kV, in particular of at least 20 kV, e.g., of at least 30 kV, preferably of a voltage in the range of 30 kV to 40 kV.

[0077] The effect of a particularly homogeneous plasma-activation of the carrier mesh and, as a consequence, of a particularly homogenously distributed improvement of the tuft bind, can be inferred e.g., from the tuft bind standard deviations illustrated in figures 9A and 9B.

[0078] In yet another embodiment, the dielectric barrier discharge is applied at an energy density of at least 0.1 J/cm^2, in particular of at least 0.3 J/cm^2, in particular of at least 0.5 J/cm^2, and in particular between 0.5 J cm^2 and 0.6 J/cm^2 to the backside of the carrier mesh. For backing layers applied to the backside between about 650 - 700 g/m^2, and with the carrier mesh having 3/4 inch gauge fibers integrated with 180 stiches/m and a pile height of 60 mm, the applied energy density between 0.5 J cm^2 and 0.6 J/cm^2 advantageously results in an optimized binding between the fibers and the applied backing layer for a DBD device having one first electrode (i.e., further increases in the applied energy density do not result in any appreciable increases in binding).

[0079] In some other embodiments, the gap between the first electrode(s) and the second electrode is adjustable, e.g., is adjustable such that a gap between the outer surface of the dielectric at least partially enchasing the second electrode and the first electrode(s) is greater than 0 mm, in particular greater than 15 mm, in particular greater than 30 mm, in particular greater than 40 mm, in particular between 40 mm and 80 mm. According to embodiments, the gap is 35 mm to 55 mm thick. The outer surface of the dielectric is the surface of the dielectric facing towards the first electrode.

[0080] For example, the gap may be greater than 0 mm, in particular greater than 10 mm, e.g., greater than 20 mm, e.g., greater than 30 mm, e.g., greater than 40 mm, e.g., greater than 50 mm, in some cases even greater than 80 mm, e.g., 100 mm in width. According to some examples, the gap between the first electrode(s) and the second electrode is adjustable such that the gap between the outer surface of the dielectric at least partially enchasing the second electrode and the first electrode(s) is less than 100 mm, e.g., less than 80 mm, preferably less than 50 mm, e.g., less than 10 mm in width.

[0081] Without wishing to be bound by any theory, the applicant believes that the dielectric enchasing the second electrode makes it possible to design and use a plasma activation device which allows the width of the air gap between the surface of the dielectric and the first electrodes to be adjusted over a wide range, thereby allowing plasma activation even of greige goods which are several centimeters thick and have a very uneven surface. This is because the dielectric makes it possible to generate a stable high voltage field, high enough for effective plasma activation even when the distance between the two electrodes is large, while at the same time preventing strong discharges at individual points where the tuft rows or other protrusions may come into contact with the first electrodes.

[0082] According to some examples, the gap can be adjustable such that a distance between the backside of the carrier mesh and the first electrode(s) of less than 10 mm, preferably less than 5 mm is formed. An adjustable distance allows for receiving different carrier meshes in the air gap of the DBD device having different widths and/or accommodating in the gap a single carrier mesh that has varying mesh widths (e.g., due to mesh manufacturing inconsistencies), and/or allows for efficient adjustment to accommodate for different ambient conditions, such as temperature and humidity, or different

voltages applied to the first electrode. For example, the adjustment may be performed before or while performing the plasma-activation. To allow for a strong plasma-activation, the distance between the carrier mesh backside and the first electrodes(s) should be very small, e.g., smaller than 5 mm, e.g., only 1-3 mm, or even 0 mm. Hence, in some embodiments, the dielectric barrier discharge device may comprise a first electrode positioned such that the distance between the first electrode(s) and the surface of the backside of the carrier mesh and the fiber portions protruding therefrom is zero, meaning that the first electrode(s) will contact the backside of the carrier mesh and the fiber portions. However, a downside of this configuration may be that the contacts may induce an at least partial local discharge and hence to a less homogeneous plasma-activation. Hence, according to other embodiments, the dielectric barrier discharge device is configured such that the distance between the first electrode(s) and the surface of the backside of the carrier mesh and the fiber portions protruding therefrom is approximately 1 mm to 5 mm, in particular 1 mm to 3 mm. This may reduce the frequency of intermittent local contacts and a partial discharge of the first electrode. The position of the first electrode may be the result of an adjustment of the gap or may be in accordance with the original device architecture.

[0083] Hence, the dielectric barrier discharge device preferably allows adjusting the distance of the first and second electrodes such that the carrier mesh with the integrated fibers can be transported through the air gap formed between the surface of the dielectric and the first electrode in one or more of the following two modes: a contact-less mode where the surface of the backside of the carrier mesh and the fiber portions protruding therefrom do not touch the first electrode (except for very rare events where an individual tuft row may be exceptionally high); and an in-contact mode, where the surface of the backside of the carrier mesh and the fiber portions protruding therefrom touch the first electrode at one or more locations or even are in full contact with the first electrode.

[0084] In some embodiments, the dielectric barrier discharge device is configured such that the distance between the first electrode(s) and the surface of the backside of the carrier mesh and the fiber portions protruding therefrom is below 10 mm, in particular below 5 mm. For example, the distance may be such that the carrier mesh can be transported through the air gap formed by the surface of the dielectric and the first electrode such that approximately no contact with the first electrode occurs, or such that the first electrode is (continuously and/or on one or more locations) contacted by the backside of the carrier mesh and the fiber portions protruding therefrom.

[0085] In general, the use of the dielectric will ensure that even in case of a local contact of the first electrode with the backside of the carrier mesh/a tuft row results in a local discharge, the discharge of the first electrode will not be complete as the effect of the local contact on the voltage field is typically very small relative to the effect of the dielectric which maintains the high voltage field and prevents a sudden complete discharge when a local contact occurs.

[0086] In one embodiment, the DBD device comprises one or more distance sensors configured to continuously monitor the carrier mesh which is to be fed into the air gap in order to determine if there exist any objects or elevations in the surface of the carrier mesh/greige good (e.g. particularly high tuft rows or foreign bodies that have got into the production process) which could collide with and damage the first electrode. In case the sensor(s) detect such an object or elevation, a controller of the DBD device automatically increases the air gap between the first electrode and the surface of the dielectric as to avoid a collision, or automatically stops the movement of the carrier mesh.

[0087] In one embodiment, the dielectric barrier discharge device is controlled to continuously apply the dielectric barrier discharge (to the backside of the carrier mesh and at least some of the fiber portions protruding therefrom) for plasma-activating the backside (the backside of the carrier mesh and at least some of the fiber portions protruding therefrom, e.g., fiber portions forming tuft row surfaces which are exposed to the plasma activation).

[0088] In one embodiment, the method is part of a continuously executed, inline roll-to-roll production process comprising: unrolling a carrier mesh roll; tufting the fibers into the unrolled carrier mesh; performing the method according to any one of the previous claims for providing the artificial turf; and forming an artificial turf roll from the provided artificial turf. This may advantageously ensure that the backing is applied shortly after the plasma activation step and the whole roll-to-roll manufacturing process can be executed fully automatically or semi-automatically with minimum delay and highly efficiently.

[0089] In one embodiment, plasma-activating the backside enables a formation of covalent bonds between the backside and the applied backing layer for providing increased binding between the fibers and the applied backing layer.

[0090] In other embodiments, the fibers include polyethylene or polypropylene and/or the carrier mesh includes polypropylene.

[0091] In some embodiments, the backing layer is applied in the form of a liquid or fluid mass. For example, the backing layer may be polyurethane or latex.

[0092] According to embodiments, the backing layer is applied in an amount such that in the dried state, there is at least 200 g polyurethane or latex material per m2 artificial turf. According to some embodiments, the backing layer is applied in an amount such that in the dried state, there is about 200 g - 800 g, e.g., about 300 g to 650 g polyurethane or latex material per m2 artificial turf. Applicant has observed that thanks to the plasma activation, also for artificial turf types using a small amount of latex or polyurethane of less than 600 g/m2, a tuft bind of

over 50 N (after pre-processed the artificial turf according to DIN EN 13744 and then determining the tuft withdrawal force according to FIFA Test Method 26) can be achieved. For example, the tuft binding force can be measured as the force required to pull out a whole tuft bundle and a tuft bind of over 50 N (after pre-processed the artificial turf according to DIN EN 13744 and then determining the tuft withdrawal force according to FIFA Test Method 26) can be achieved.

[0093] According to embodiments, the artificial turf comprises less than 600g/m2 of a latex or polyurethane backing, in particular less than 350 g/m2 of the latex or polyurethane backing, and a tuft withdrawal force of over 40 N, in particular over 50 N (after pre-processed the artificial turf according to DIN EN 13744 and then determining the tuft withdrawal force according to FIFA Test Method 26).

[0094] In some embodiments, the backside forms a non-planar surface. For example, it may comprise multiple tuft rows Advantageously, the DBD device having a first and second electrode and a dielectric at least partially surrounding the second electrode applies the plasma discharge more uniformly over the backside of a non-planar carrier mesh, as well as over the backside of a planar mesh, resulting in a more homogeneous distribution of plasma-activated sites on the backside, as compared, e.g., to a corona discharge process.

[0095] In one aspect, an artificial turf is obtainable (i.e., manufactured) according to any one of the above processes.

[0096] In yet another aspect, an artificial turf includes a carrier mesh, where the carrier mesh includes a backside, and where the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside, and a plasma-discharge-assisted homogenously-distributed backing layer positioned on the backside of the carrier mesh and attached to the backside via a homogeneous distribution of binding forces between the backside surface of the carrier mesh and the backing layer.

[0097] For example, the homogeneous distribution of binding forces between the backside of the carrier mesh and the backing layer is the result of a homogenous distribution of ions forming covalent bonds between the backside of the carrier mesh and the backing layer.

[0098] In particular, the homogeneous distribution of binding forces between the backside of the carrier mesh and the backing layer may comprise a homogeneous distribution of tuft binding forces between a) the backside of the carrier mesh and the exposed fibers on the backside of the carrier mesh and b) the backing layer.

[0099] According to some examples, the binding force is a tuft binding force determined by pre-processing the artificial turf according to DIN EN 13744 and then determining the tuft withdrawal force according to FIFA Test Method 26, whereby the tuft binding force is at least 40 N, in particular at least 50 N.

[0100] According to some examples, the backside of the carrier mesh contacting the backing is a continuously plasma-treated side of the carrier mesh.

[0101] In yet another aspect, disclosed herein is a further method of manufacturing an artificial turf and a system used for performing the method. The method comprises: moving a carrier through an air gap formed between a first electrode and a second electrode of a dielectric barrier discharge device; applying a dielectric barrier discharge to one side of the carrier for plasma-activating the side; and using the plasma-activated carrier for manufacturing the artificial turf.

[0102] For example, the carrier can be a carrier mesh or a carrier foil. The plasma-activated side may be a backside of the carrier (opposed to the side from which the longer parts of the artificial turf fibers will protrude once the fibers have been integrated). According to some examples, the use of the plasma-activated carrier for manufacturing the artificial turf comprises integrating artificial turf fibers into the plasma-activated carrier, e.g., by means of tufting, weaving, knitting or other types of fiber insertion techniques, and then applying the backing. The dielectric barrier discharge may be applied as described herein for the other embodiments and examples described herein.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0103] The following embodiments of the invention are explained in greater detail, by way of example only, making reference to the drawings in which:

Fig. 1 shows a production line system for manufacturing an artificial turf, according to an embodiment of the present invention;

Fig. 2 illustrates a portion of the carrier mesh of Fig. 1 after exiting the fiber inserter of Fig. 1, according to an embodiment of the invention;

Fig. 3 illustrates a portion of the carrier mesh of Fig. 1 after exiting the dispensing unit of Fig. 1, according to an embodiment of the invention;

Fig. 4 shows a y-z cross section of the DBD device of Fig. 1, and the control unit 114 of Fig. 1, according to an embodiment of the invention;

Fig. 5 shows a z-x cross-sectional view of the DBD device of Fig. 1, according to an embodiment of the invention;

Fig. 6 shows an overhead perspective view of the DBD device of Fig. 1, according to an embodiment of the invention which uses two wires as first electrodes;

Fig. 7 illustrates a method for method of manufactur-

ing an artificial turf, according to an embodiment of the invention;

Fig. 8 is an illustration of the plasma activation process using a metal bar; and

Fig. 9 shows experimental data obtained for samples of artificial turf.

DETAILED DESCRIPTION OF THE INVENTION

[0104] The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

[0105] Fig. 1 shows a production line system 100 for manufacturing an artificial turf, according to an embodiment of the present invention. The system includes a fiber inserter 102 configured to receive an artificial turf carrier mesh 104 and artificial turf fiber 106, and insert the artificial turf fiber 106 into the carrier mesh 104, by, for example, weaving or tufting the fiber into the carrier mesh 104. In some embodiments, the fibers include polyethylene or polypropylene and the carrier mesh comprises polypropylene. In other embodiments, the carrier mesh is or comprises a mixture of different polymer fibers, e.g., polypropylene fibers, polyethylene fibers and/or polyamide fibers.

[0106] The carrier mesh is also referred to as primary backing. The production line system 100 includes a conveyor assembly 107, including conventional rollers 108, as well other conventional components used in conveyor assemblies, such as drive systems (not shown) for driving one or more of the rollers 108, transport platforms (not shown), etc., configured in combination to move the carrier mesh to (and or through) each processing station, such as through the fiber inserter processing station 102.

[0107] Fig. 2 illustrates a portion of the carrier mesh 104 at location 110 in the system 100 after exiting the fiber inserter 102, according to an embodiment of the invention. In the embodiment illustrated, the carrier mesh 104 includes fibers 106 that have been tufted into the carrier mesh 104. It can be seen that a small loop of tuft fiber 202 extends (i.e., is exposed) on a backside 204 of the carrier mesh 104. Each series of the most closely spaced exposed tuft fibers 202 form a tuft row 210. The distance between two tuft rows can be, for example, 0.2 cm to 2.0 cm, e.g., about 0.25 cm, 0.5 cm or 1.0 cm. The tufted fibers 106 form a pile surface 206 on a front side 208 of the carrier mesh 104.

[0108] Referring again to Fig. 1, the system 100 includes a dielectric barrier discharge (DBD) device 112 and a control unit 114. As will be discussed in further detail below in conjunction with Fig. 4, the control unit 114 is configured to control the DBD device 112 to apply a dielectric barrier (i.e., plasma) discharge to the backside 204 of the carrier mesh 104 as the carrier mesh 104 moves through the DBD device 112 for plasma-activating the backside 204 in preparation for applying a backing layer, also referred to in the art as a secondary backing or secondary backing layer, by a dispensing unit 116.

[0109] As noted, the dispensing unit 116 applies a backing layer to the plasma-activated backside 204 of the carrier mesh 104. Fig. 3 illustrates a portion of the carrier mesh at location 119 of the system 100, after exiting the dispensing unit 116, according to an embodiment of the invention. Fig. 3 is identical to Fig. 2, with the additional feature of a backing layer coating 302 (e.g., a polyurethane or a colloidal latex backing layer coating) that has been applied to the plasma-activated backside 204 by the dispensing unit 116. The backing layer coating 302, also referred to as a backing layer 302, covers tufted regions (i.e., those regions containing the loops 202), well as the other remaining non-tufted regions of the plasma-activated backside 204 of the carrier mesh 104.

[0110] Referring again to Fig. 1, the dispensing unit 116 is configured to coat the plasma-activated backside 204 of the carrier mesh 104 with a polyurethane or latex 118. In one embodiment, the latex 118 is a colloidal latex, however, the polyurethane may be applied as a liquid or a foam. In the exemplary embodiment illustrated, the dispensing unit 116 is a lick roll including a rotating element 122 used to apply the polyurethane or colloidal latex 118 to the plasma-activated backside 204 of the carrier mesh 104. However, the scope of the invention includes other means of applying the coating 302. For example, and in another exemplary embodiment, the dispensing unit 116 is configured as a knife-over-roll dispensing unit (not shown) for first applying the polyurethane or the colloidal latex onto the plasma-activated backside 204 and then leveling the applied material using the conventional knife-over-roll process. When a knife-over-roll technique is used, the greige good typically has a different orientation, such that the side from which the fibers protrude faces downwards, allowing to apply the liquid backing by pouring or spraying it onto the opposite, upwards-facing side.

[0111] The system 110 may optionally include an anti-blistering applicator 122, configured in one embodiment as a spray bar. However, the scope of the invention covers any apparatus/process of applying a preferably small amount of anti-blistering agent 124 to the polyurethane or colloidal latex coating (i.e., to the backing layer coating 302) on the backside 204 of the carrier mesh 104. As illustrated, the applicator 122 is configured to wet a region 126 of the backing layer 302 with the anti-blistering agent 124.

[0112] Th system optionally includes a heater 128. The

heater has an entrance 130 and an exit 132. The applicator 122 may be configured such that the wet region 126 is a distance 134 from the entrance 130 of the heater 128. The system 100 is configured to control the distance 134, via moving the heater 128 or the applicator 122, to control the time period between application of the anti-blistering agent 122 to any region of the carrier mesh 104 and entry of this region into the heater 128 via entrance 130. Time periods may vary depending upon ambient environmental conditions, such as ambient temperatures, relative humidity, etc. In one embodiment, the heater 128 and/or the applicator 122 are configured to be moveably-adjustable along the path of motion of the carrier mesh 104 on the conveyor assembly 107 for adjusting, either manually by an operator or automatically by the system (e.g., by the control unit 114, based upon operator input and/or sensor data), the distance 134.

[0113] The heater 128 is configured to remove water from the backing layer coating 302, thereby curing it for forming a solid backing layer 136. In one embodiment, when the artificial turf carrier mesh 104 exits the heater 128, the manufacturing of the artificial turf by the system 100 is complete, although in additional optional embodiments, the artificial turf fibers 106 may be trimmed after leaving the heater 128. Furthermore, in other embodiments, the backing layer coating 302 may cure before reaching the heater 128 and/or applicator 122, as a result of conditions of the ambient environment, which may be controlled by an operator, and/or length of time after being applied by the dispensing unit 116, and thus the manufacturing of the artificial turf by the system 100 is considered complete before reaching the heater 128 or the applicator 122. In one embodiment, the artificial turf mesh 104 with the integrated fibers 106 and the backing layer 302 exiting the dispensing unit 116 is the manufactured artificial turf of the present invention. In other embodiments, the artificial turf mesh 104 with the integrated fibers 106 and the backing layer 302 exiting the applicator 122 or the heater 128 is the manufactured artificial turf of the present invention.

[0114] The heater 128 may function in different ways. In the illustrated exemplary embodiment, the heater 128 has a first heat control element 138 and a second heat control element 140. The first heat control element 138 generates forced air 142 with a first temperature range and the second heat control element 140 generates forced air 144 with a second temperature range. In this way, the temperature of the backside 204 can be controlled to be different from that of the frontside 206 during the curing process. This may lead to effective removal of water from the backing layer coating 302 while protecting the artificial turf fibers 106 against high temperatures.

[0115] The manufacturing process and the system for manufacturing an artificial turf depicted in figure 1 comprises a fiber inserter 102. However, according to other embodiments (not shown), the artificial turf is manufacture in a roll-to-roll process and the system is free of a fiber inserter 102 or the fiber inserter is not used. For example, the manufacturing process described with reference to figure 1 may start with unrolling a roll of greige good (a carrier mesh comprising the already integrated fibers, but being free of a backing layer) and the unrolled greige good is fed into the air gap of the dielectric barrier discharge device. Then, the backside of the greige good (opposite to the side from which the fibers protrude) is plasma-activated using a dielectric barrier discharge technique, the liquid backing is applied onto the plasma-activated backside, optionally dried in an oven, and then rolled up to provide a roll of artificial turf.

[0116] Fig. 4 shows a y-z cross section of the DBD device 112 of Fig. 1, and the control unit 114, according to an embodiment of the invention. The DBD device 112 includes a first electrode 402 and a second electrode 404, and is illustrated with the carrier mesh 104 partially occupying an air gap g 405 formed between the first and second electrodes 402, 404, as discussed further below. The first and second electrodes 402, 404 are oriented parallel to one another (i.e., both electrodes are elongated in a same first direction 406, or in other words, have longitudinal axes of symmetry, also referred to as major axes of symmetry, that are oriented in the same first direction).

[0117] In one embodiment, the first electrode 402 is adjacent to the backside 204 (also referred to as the backside surface 204) of the carrier mesh 104, the second electrode 404 is adjacent to the frontside 208 of the carrier mesh 104, and the second electrode 404 is at least partially encased in a dielectric 408. In embodiments, the dielectric 408 is formed of (homogeneously-distributed) dielectric plastic material. In one embodiment, and as measured from the second electrode 404, the dielectric extends a width/thickness in at least in a second direction 412 (i.e., in the -z direction) towards the first electrode 402, where the second direction 412 is perpendicular to the first direction 406. In an embodiment, the air gap g 405 is formed between a bottom edge 413 of the dielectric (i.e., the edge or surface closest to the first electrode 402) and the first electrode. As illustrated, the air gap g 405 is partially occupied by the carrier mesh 104 with the integrated fibers 106, which is being fed though the air gap 405 by the conveyor assembly 107.

[0118] The conveyor assembly 107 is configured to move the carrier mesh 104 with the integrated fibers 106 in a third direction 414 (i.e., into or out of the plane of Fig. 4) that is orthogonal to both the first and second directions 406, 412. In one embodiment, the conveyor assembly 107 transports the carrier mesh 104 through the air gap 405 at a speed between 5-15 m/min, preferably between 6-12 m/min, and more preferably between 6-9 m/min. In one embodiment, the speed is dependent upon one or more parameters of the dispensing unit 116 (e.g., a rate at which the backing layer 302 is applied to the plasma-activated backside 204 of the carrier mesh 104).

[0119] In another embodiment, the conveyor assembly 107 is configured to move the carrier mesh 104 through

the air gap 405 at a manually-adjustable and/or an automatically-adjustable speed. For example, the speed may be adjusted by operator input to the control unit 114, and/or the control unit 114 may include software that is configured to automatically determine and/or adjust the speed of the conveyor assembly 107 based upon data input by an operator and/or upon data collected from system sensors, e.g., rate of application of the backing layer mixture 118 from the dispensing unit 116 and/or power applied to the backside 204 of the carrier mesh 104 as a plasma discharge from the DBD device 112. Optionally, the system 112 may comprise one or more distance sensors configured to identify if the carrier mesh comprises any elevations or attached objects which might, upon reaching the first electrode, collide and potentially damage the first electrode. In this case, the controller operatively coupled to the distance sensor(s) to increase the width of the air gap or to stop the movement of the carrier mesh as to prevent the first electrodes being damaged. The distance sensors can be, for example, optical sensors, e.g. cameras, or laser-based distance sensors, or ultrasonic signal based distance sensors, capacitive distance sensors, etc.

[0120] In one embodiment, a single electrode, i.e., the first electrode 402 of the DBD device 112, is electrically coupled to the control unit 114 via a power lead 416. The power lead 114 supplies a voltage to the first electrode, resulting in the DBD device 112 generating a plasma discharge, also referred to as a dielectric barrier discharge, that is directed to (i.e., applied to) the backside 204 of the carrier mesh 104 for plasma-activating the backside 204. In other embodiments, two or more power leads 416 (not shown) are coupled between the control unit 114 and two or more positions along the first electrode 402.

[0121] In another embodiment, the DBD device 112 includes a support structure 418 that is configured to be non-electrically (e.g., mechanically) coupled to the first electrode 402 at one or more positions along the first electrode 402, or as illustrated, at two end points 420 of the first electrode 402, for supporting a positioning of the first electrode 402 with respect to the second electrode 404 and with respect to the bottom edge 413 of the dielectric 408 that at least partially encases the second electrode 404, and for setting a width of the air gap g 405. In one embodiment, the support structure 418 is configured to be manually adjustable in at least a vertical direction (i.e., in the z direction 412). Control of the support structure 418 by the control unit 114 will be discussed in more detail further below.

[0122] In some embodiments, the thickness of the dielectric 408 is between 0.2 cm to 10.0 cm, e.g., about 2.0-3.0 cm. In other embodiments, given a known carrier mesh width wc 422, as measured from the backside 204 to the frontside 208 of the carrier mesh 104 in a state when the frontside of the carrier mesh rests on a surface, e.g. a roll, and the fiber portions to form the turf are compressed, the air gap g 405 has a width which results in a distance rg 424 measured between the backside 204 of the carrier mesh and the first electrode 402 that is typically less than 1.0 cm, e.g. less than 0.5 cm and preferably less than 0.3 cm. Preferably, the distance 424 of the first electrode(s) is chosen such that a direct contact of the first electrode(s) and the carrier mesh is avoided. However, applicant has observed that due to the uneven surface and the tuft rows, direct contact may not always be avoided, and in some use case scenarios, even a distance 424 of 0 mm, i.e., a basically contact-based configuration of the plasma discharge device, may successfully be used. Surprisingly, applicant has observed that even in case the first electrode occasionally or continuously touches the surface of the carrier mesh, the plasma activation effect is nevertheless distributed homogeneously over the whole length of the first electrode(s), and hence homogeneously over the whole area of the carrier mesh treated. This may be the result of the use of the dielectric enchasing the second electrode, because this dielectric typically has a higher dielectric constant than the material (greige good, carrier) transported through the air gap and prevents the first electrodes to discharge in case the first electrode(s) occasionally or continuously contact the greige good or carrier.

[0123] In embodiments, the first electrode 402, also referred to as a counter electrode, the second electrode 404 and the carrier mesh 104 each have at length l 426 of 4 meters. However, the scope of the invention covers counter electrodes, electrodes and/or carrier meshes having different lengths (i.e., smaller and larger).

[0124] In one embodiment, the dielectric 408is a hollow cylinder (or a partial cylinder) that is centered about and extended along a cylinder of metal used as the second electrode 404. However, the scope of the invention includes dielectrics having other shapes, such as elliptical or rectangular. In other embodiments, and particularly for hollow-cylindrically-shaped dielectrics having the second electrode 404 positioned at their respective longitudinal (i.e., major) axes of symmetry, the second electrode 404 including the dielectric 408surrounds (or at least partially surrounds) the second electrode 404 and is vertically positioned (i.e., positioned in the z direction 412) within the DBD device 112 such that the frontside 206 of the carrier mesh 104 makes contact with the bottom edge 413 (or surface) of the dielectric (i.e., edge (or surface) closest to the first electrode 402) such that the complete cylinder 408 rotates about its longitudinal axis as the carrier mesh 104 is moved through the air gap 405 of the DBD device 112 by the conveyor assembly 107.

[0125] In one embodiment, the static frictional force between the frontside 208 of the carrier mesh 104 and the dielectric 408is large enough to cause the dielectric 408to rotate about the second electrode 404 as the carrier mesh 104 is moved through the air gap 405 of the DBD device 112 by the conveyor assembly 107 without any slippage between the portions of the dielectric 408 in contact with the frontside 208 of the carrier mesh 104 and

the frontside 208 of the carrier mesh 104. Advantageously, neither the frontside 208 of the carrier mesh 104, nor the dielectric 408 surrounding the second electrode 404, build up a static electrical charge. However, if there is slippage (i.e., relative motion) between the carrier mesh 104 and those surface portions of the dielectric in contact with the carrier mesh 104, then the dynamic frictional forces cause by one material contacting and moving with respect to a second material may generate heat, static electricity, and a static voltage potential between the two materials, thereby compromising a uniform distribution of the dielectric barrier discharge (i.e., the plasma discharge) across the backside 204 of the carrier mesh 104, as well as compromising application of the discharge at desired controlled voltages and/or desired controlled temperatures.

[0126] The control unit 114 includes a controller 426, a positioning system 428, and a power source 430, such as a transformer. The controller 426 is configured to control the DBD device 112 for applying a dielectric barrier discharge to the backside 204 of the carrier mesh 104 as the carrier mesh 104 moves through the air gap 405 for plasma-activating the backside 204. In one embodiment, the controller 426 controls the DBD device 112 to continuously apply a plasma discharge to the backside 204 of the mesh 104 as the mesh 104 moves through the air gap 405. In one embodiment, the controller 426 is configured to enable the power source 430 to apply, via one or more power switches (not shown), a voltage of up to and including 40 kV to the first electrode 402 of the DBD device 112 via the power lead 416.

[0127] In an exemplary embodiment, the controller 426 controls the DBD device 112 to continuously apply a plasma discharge to the backside 204 of the mesh 104 as the mesh 104 moves through the air gap 405 at an energy density of between 0.5 J cm^2 and 0.6 J/cm^2. In one embodiment, the DBD device 112 delivers the plasma discharge at a power between 500 and 600 Watts as the conveyor assembly 107 moves the mesh at a speed of 6 m/min for applying an energy density of between 0.5 J cm^2 and 0.6 J/cm^2 to the backside 204 of the mesh 104. The energy density can be adjusted by controlling the speed of the conveyor assembly 107 and the applied power. For example, decreasing the applied power and/or increasing the conveyor speed reduces the energy density applied to the backside 204 of the mesh 104.

[0128] In one embodiment, the control unit 114 is configured to control the dielectric barrier discharge device 122 to apply the dielectric barrier discharge for plasma-activating the backside 204 by enabling the formation of covalent bonds between the backside 204 and the backing layer coating 302, as applied by the dispensing unit 116 after the backside 204 is plasma-activated, for providing increased binding between the fibers 106 of the carrier mesh 104 and the applied backing layer 302. In particular, the portions of the fibers exposed on the backside of the carrier mesh (e.g., for fibers tufted into the carrier mesh, as illustrated by Fig. 2, portions of the fibers 202 exposed in the tuft rows 210 on the backside of the carrier mesh), are activated by the plasma discharge (i.e., by the bombardment of the mesh backside 204 (i.e., the backside surface) by high energy ions from the plasma formed in the air gap 405), or in other words, enabling the mesh backside 204 (at an atomic/molecular level) to be receptive to the formation of covalent bonds with the backing layer 302, which is applied shortly thereafter.

[0129] In contrast to a corona discharge system, the dielectric 408 of the DBD device 112 limits current flow and distributes the plasma discharge more uniformly over the backside 204 of the carrier mesh 104, thereby enabling the formation of a more homogeneous distribution of covalent binding between the backside 204 and applied backing layer 302, resulting in an overall improvement in the strength of attachment between the backing layer 302 and the fibers 106 of the carrier mesh.

[0130] In one embodiment, the system 100 is configured, e.g., via selection of the speed of the conveyor assembly 107 and/or selection of distances between the DBD device 112 and the dispensing unit 116, such that the dispensing unit 116 applies the backing layer coating to a portion of the plasma-activated backside 204 of the carrier mesh 104 within a few hours or preferably a few minutes after plasma activation of that portion by the DBD device 112, so that a significant number of plasma-enhanced receptive sites are still available for forming respective covalent bonds with the backing layer 302 when applied. In one embodiment, a maximum time period for applying the backing layer 302 to a portion of the plasma-activated backside 204 of the carrier mesh 104 is 5 minutes after plasma activation of that portion by the DBD device 112.

[0131] In yet another embodiment, the positioning system 428 is coupled to the support structure 418 of the DBD device 112 for moving the support structure 418 in at least a vertical up-down direction (in direction 412). In one embodiment, the positioning system 428 is a distributed positioning system 428 that includes one or more of servos, actuators, switches (mechanical and/or electrical), signal/control lines for transmitting electrical, pneumatic and/or hydraulic control signals for operating the servos and actuators, and sensors, or any combination thereof, distributed throughout the system 100 for moving components of the system 100, such as moving the support structure 418 for adjusting/setting the width of the air gap 405. In other embodiments, the positioning system 428 is configured to also adjust/set other system parameters, without moving any of the system components, such as adjusting/setting the speed of the conveyor assembly 107 for moving the carrier mesh 104, via control/power signals to electrical motors for driving the conveyor assembly 107.

[0132] The controller 426 may be configured, e.g., with a user input interface, such that an operator may manually enter data that instructs the controller 426 to adjust the air gap 405, via the positioning system 428, to a desired width. The desired width of the air gap 405

may be based upon one or more of: the voltage to be applied to the first electrode 402, the speed at which the carrier mesh 104 is moved through the air gap 405, the thickness of the dielectric 408, the type of material of the dielectric 408 and/or carrier mesh 104, the width wc 422 of the carrier mesh, the distance rg 424 measured between the backside 204 of the carrier mesh 104 and the first electrode 402, or the ambient environment of the DBD device 112 (e.g., ambient temperature, humidity, etc.), or any combination thereof.

[0133] In another embodiment, or in addition to the embodiment of the controller 426 being configured with a user interface, the controller 426 includes software that is configured to automatically determine a desired width of the air gap 405 based on, e.g., operator input to the controller 426, as described above, and/or on data collected by system sensors (not shown) of the distributed positioning system 428. For example, the distribute positioning system 428 may optionally include a motion sensor and/or a width sensor for detecting the speed of the carrier mesh 104 through the air gap 405 and/or the width wc 422 of the carrier mesh 100 integrated with the fibers 106. Motion sensors are well known in the art and will not be discussed in further detail.

[0134] In one embodiment, a width sensor includes a vertically-moveable mechanical arm that moves in a vertical direction 412 as it remains in contact with the backside 204 of the carrier mesh 104 at a location in the system 100 before the carrier mesh 104 enters the air gap 405. Based on a current vertical position of the moveable arm, a known average width of the carrier mesh 104 integrated with the fibers 106, and the speed of the mesh 104 along the conveyor assembly 107, the controller 426 determines the desired width of the air gap 405 and instructs the positioning system 428 to continuously adjust the air gap width such that the distance rg 424 measured between the backside 204 of the carrier mesh 104 and the first electrode 402 is constant, or essentially constant.

[0135] Since carrier meshes may have some width irregularities, the controller 426, using the data received from the width sensor, corrects for width irregularities, thereby ensuring that the distance rg 424 remains essentially at a constant desired value when the plasma discharge is applied to the mesh 104 as the mesh 104 moves through the air gap 405.

[0136] In other embodiments, the width sensor of the positioning system 428 is a camera that captures images of either the backside 204 of the carrier mesh 104 or the entire carrier mesh 104 (bounded by the front and backsides 208, 204), as the carrier mesh 104 moves past the camera before the mesh 104 enters the air gap 405. The controller 426 receives the captured images, and using, e.g., edge detection software, detects the vertical position of the backside 204 (and/or frontside 208) of the mesh 104, determines width irregularities in the mesh 104, and instructs the positioning system 428 to adjust the position of the first electrode 402 to keep the distance rg 424 at an essentially constant desired value as the mesh 104 moves through the air gap 405 to receive the plasma discharge.

[0137] As mentioned above, the system 112 may comprise one or more distance sensors for identifying the distance of elevations or objects which might collide with the first electrode. The controller may be configured to adjust the width of the airgap, e.g. via the position of the first electrode, based on the measurement data obtained from the distance sensors, such that a collision is prevented.

[0138] In embodiments in which the carrier mesh 104 includes the fibers 106 tufted into the backside 204, the distance rg 424 is measured between the portions of the fibers elevated above the backside 204 of the mesh 104 (as a result of the fibers being tufted into the mesh 104) and the first electrode 402. In one embodiment, the backside 204 forms a non-planar surface, where the tuft rows 210 form tufted regions elevated above the other non-tufted regions of the carrier mesh 104. However, the scope of the present invention covers carrier meshes 104 including other types of fiber integration. For example, in another embodiment, the carrier mesh 104 includes fibers incorporated by weaving the fibers into the carrier mesh. Whether the fibers are woven or tufted into the carrier mesh 104, the scope of the present invention covers planar and non-planar carrier mesh backsides 204. In one embodiment, the carrier mesh 104 is positioned on the carrier assembly 107 such that the tuft rows 210 are parallel to the direction of motion of the carrier mesh 104 though the DBD device 112.

[0139] Fig. 5 shows a z-x cross-sectional view of the DBD device 112 of Fig. 1, according to an embodiment of the invention. Reference numbers that are the same as those used in conjunction with Figs. 1 and 4 reference the same elements. For ease of illustration, the support structure 418 and power lead 416 are not shown.

[0140] As illustrated, the DBD device 112 includes the second electrode 404 surrounded by the dielectric 408, formed as a hollow cylinder of dielectric material having a bottom edge 413 (i.e., portion of dielectric surface) contacting the frontside 208 of the carrier mesh 104. The whole cylinder comprising the second electrode and the dielectric is rotatable about the longitudinal axis of the whole cylinder. The DBD device 112 includes the first electrode 402, and may optionally include one or more additional first electrodes, all aligned parallel to one another (all longitudinally extended in the same direction). In the exemplary embodiment as illustrated, the DBD device 112 includes two additional first electrodes 502 and 504. However, the scope of the invention covers other embodiments having any number of parallel oriented first electrodes. Although not shown, each of the optional first electrodes 502 and 504 are coupled to the support structural 418 for support and vertical location adjustment, and with the power supply 430 via the power lead 416. Preferably, the first electrodes are galvanically decoupled from each other.

[0141] Advantageously, by using two (or more) parallel first electrodes, e.g., 402, 502, 504, plasma activation of the backside 204, as well as binding between the backside 204 and the applied backing layer 302, is increased due to the increase in total surface area provided by the additional first electrodes, resulting in an increase in the volume of air in the portion of the air gap 405 (that is not occupied by the mesh 104, (i.e., the volume contained within the distance rg 424)) that is transformed into a plasma before the transformation is halted by plasma saturation within the air gap. That is, the volume of air in the gap that can be transformed into a plasma is limited by the number of first electrodes, independent of increasing the applied power above a maximum value corresponding to the onset of plasma saturation. For example, a DBD device including one first electrode may result in maximum binding at 600 Watts, with no appreciable improvement in binding at powers greater than 600 Watts. However, a DBD device having two or more first electrodes operating at 600 Watts has a greater volume of air in the gap before plasma saturation of the gap occurs, and thus an improvement in binding at 600 Watts in comparison, and a possible additional improvement in binding for powers greater the 600 Watts up to a higher maximum power limit. A further advantage may be that in case the voltage field of one first electrode partially breaks down or is reduced due to a contact with the carrier mesh and a resulting partial discharge, the voltage field to the other first electrode(s) remains unaffected, thereby ensuring that the plasma-activation is

[0142] According to additional embodiments, a system of the present invention includes the dielectric barrier discharge device 112, the conveyor assembly 107, the control unit 114 and the dispensing unit 116 of Fig. 1, either formed as a separate production line system independent of the production line system 100, or formed as a system including the individual components 112, 107, 114, and 116 (or alternatively the individual components 112, 114 and 116) configured not as a production line or part of a production line.

[0143] Fig. 6 shows an overhead perspective view of the DBD device 112 of Fig. 1, according to an embodiment of the invention. The DBD device 112 includes two first electrodes 602, 604, where each first electrode is the same as the first electrode 402 (Fig. 4), the dielectric 408 formed as a cylinder that completely surrounds (i.e., encases) the second electrode 404, which is not visible, and the air gap 405 through which the carrier mesh 104 (not shown) is moved. The two first electrodes 602, 604 preferably are parallel metal wires galvanically decoupled from each other.

[0144] Fig. 7 illustrates a method 700 for method of manufacturing an artificial turf, according to an embodiment of the invention.

[0145] In step 702, a carrier mesh 104 is moved through an air gap 405 formed between a first electrode 402 and a second electrode 404 of a dielectric barrier discharge device 112. The carrier mesh 104 includes a backside 204, and the carrier mesh 104 includes fibers 106 integrated such that a portion 202 of the fibers 106 are exposed on the backside 204.

[0146] In step 704, a dielectric barrier discharge is applied to the backside 204 of the carrier mesh 104 for plasma-activating the backside 204.

[0147] In step 706, a backing layer 302 is applied to the plasma-activated backside 204 of the carrier mesh 104 for providing an artificial turf.

[0148] Fig. 8 is an illustration of the plasma activation process. It shows the side of a carrier mesh 960 comprising the tuft rows while the carrier mesh is moved through the air gap between the first electrode 958 and the surface of the dielectric (below the carrier mesh, not shown). In the depicted example, the first electrode is a metal profile having the shape of a rod and being held at a specific, short distance from the surface of the carrier mesh via electrically conductive bars 954. The depicted rod may have a diameter of e.g., 0.2 to 3 mm. The bars may be attached to a frame 956 and may be connected via a cable 952 to a voltage source. As can be inferred from figure 8, the first electrode may in some spots be in direct contact with the carrier mesh. Nevertheless, applicant has observed that the plasma activation results in an improved tuft bind and that this effect is homogeneously distributed over the whole surface of the plasma-treated carrier mesh.

[0149] Fig. 9A and 9B show experimental data obtained for five different artificial turfs. Some properties and process parameters are indicated in respective columns, e.g., stitches per meter, the applied power, the conveyor speed etc. The voltage used for the plasma activation of the turfs 1-5 was, respectively: 32,2 kV, 33 kV, 33,6 kV, 33,6 kV and 33,6 kV. Some turfs comprised smooth fibers, others comprised texturized fibers as indicated in column "sample fiber type".

[0150] After having plasma-activated the turfs, the liquid polyurethane backing was applied and solidified in an oven. Then, the tuft withdrawal force was measured. Some measurements were performed 24 h after the manufacturing process. Other tuft withdrawal force measurements were performed after 14 days of immersing the sample in a 70 °C water-bath (simulated aging) or after 4 weeks (incubation in dry state, no water-bath). The time point of performing the respective measurement is also indicated in the column "sample fiber type".

[0151] The tuft withdrawal force measurements were performed as specified in FIFA "Test Method 26" (Test Manual I -Test Methods: 2015 Edition - FIFA Quality Programme for Football Turf), page 81. The FIFA test 26 comprises selecting and withdrawing one whole tuft and measure the force required to completely withdraw the tuft along a predefined path.

[0152] For example, a first section of the first artificial turf was plasma-activated using a dielectric barrier discharge machine. The machine was configured to generate a voltage field of 32,2 kV between the first and second electrodes for applying 500 Watts only onto a first

section of the carrier mesh. Two other sections of the same first artificial turf were not plasma-treated (0 Watts) and used as controls. The tuft withdrawal force of the first section of the first artificial turf was measured at different times (lines 1, 4, 7) after the manufacturing process. Likewise, the tuft withdrawal force of the two other sections of the first artificial turf used as controls was measured at different times (lines 2 + 3, 5+6, 8+9) after the manufacturing process.

[0153] Three measurements were made on each of the three different sections of the artificial turf (bundle withdrawal force for sample 1, sample 2 and sample 3).

[0154] In addition, the average and standard deviation were computed for the measurement values obtained for each section of the first and the four other artificial turfs. As shown, the average force required to pull out a fiber from the carrier mesh in the plasma activated section is 56 N 24 h after the manufacturing, and the average force required to pull out a fiber from the carrier mesh in the non-plasma activated control sections is 34 and 37 N 24 h after the manufacturing of the first artificial turf. The measurements were repeated after 14 days of aging in a 70°C water bath and after 4 weeks after manufacturing (storing the artificial turf in dry state, no water-bath). The water-based aging process comprised immersing the five artificial turfs in hot water (70°C) in accordance with DIN EN 13744. According to DIN EN 13744, the artificial turf to be tested is to be completely immersed in a water bath having a temperature of 70°C plus/minus 2 °C for 334 to 338 hours (14 days). Then, the artificial turf sections to be tested were taken out of the water and prepared for performing a tuft withdrawal force test as specified in FIFA "Test Method 26" (Test Manual I -Test Methods: 2015 Edition - FIFA Quality Programme for Football Turf), page 81.

[0155] A second artificial turf was plasma-activated and used for collecting tuft withdrawal measuring data analogously, whereby the dielectric barrier discharge device was configured to apply 600 Watt on a first section of the second artificial turf while two other sections were not plasma-treated and used as controls. As for the first artificial turf, three measurements each were made on three different sections of the artificial turf (i.e., a section plasma-activated by application of the plasma discharge at 600 Watts, and two control sections (1 and 2) that did not receive the plasma discharge (i.e., 0 Watts)). As shown, the average force required to pull out a fiber from the carrier mesh in the plasma activated section is 68 N 24 h after the manufacturing, and the average force required to pull out a fiber from the carrier mesh in the non-plasma activated control sections 1 and 2 is 35 and 39 N 24 h after the manufacturing.

[0156] A third, fourth and fifth artificial turf was (partially) plasma-treated and analyzed for obtaining tuft withdrawal measurement data as described above, whereby 700 Watts were used to plasma-activate the first section of the respective turf.

[0157] The measurement results show that the fibers of the plasma-activated sections of the artificial turfs are bound more strongly to the backing-layers in comparison to the fibers of the control sections (non-activated sections), with the rate of increase in tuft-binding per unit applied power decreasing as the applied power approaches 700 Watts. A further increase in applied power results in negligible increase in tuft-binding, due to plasma-saturation of the gap. This observation was observed consistently in the measurement data obtained from all five artificial turfs shortly and several weeks after the manufacturing. In general, artificial turfs having fibers of smaller gauge, smaller pile height, and smaller number of fiber stiches per meter resulted in weaker tuft binding. The plasma-activation consistently resulted in a tremendous improvement of tuft binding over the non-activated sections.

[0158] A comparison of the tuft withdrawal forces observed 24 h after manufacturing with the test data obtained 14 days and 4 weeks after manufacturing further reveals that the tuft binding was stable and did not significantly deteriorate during the 14 days water bath at 70 °C or during the 4 weeks storage in dry state.

[0159] A comparison of the standard deviations of the bundle withdrawal forces of the untreated and the plasma-treated pieces of the artificial turfs (see the two rightmost columns and the line "mean of standard deviation) also reveals that the standard deviation of the plasma-treated samples was significantly smaller than that of the non-treated controls. This implies that the plasma-activation was able to provide a tuft bind which was not only significantly stronger than in the un-treated controls, but which was also more homogeneously distributed compared to the tuft bind of the untreated controls.

[0160] Furthermore, a long-time test for the turf number 3 for the section treated with 700 Watt was performed seven weeks after production (not shown). The tuft withdrawal force obtained after seven weeks was basically identical to the tuft withdrawal forces measured after two weeks, showing that the plasma activation resulted in a stable, long-lasting enhancement of the tuft bind.

Claims

1. A system (100) for manufacturing an artificial turf (136), comprising:

   - a dielectric barrier discharge device (112) including a first electrode (402, 602, 604, 958) and a second electrode (404);
   - a conveyor unit (108, 110, 107) configured for moving a carrier mesh (960) through an air gap (405) formed between the first electrode and the second electrode, wherein the carrier mesh includes a backside, and wherein the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside;
   - a control unit (114) configured to control the

dielectric barrier discharge device to apply a dielectric barrier discharge to the backside of the carrier mesh as the carrier mesh moves through the air gap for plasma-activating the backside; and

- a dispensing unit (116) configured to apply a backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

2. The system of claim 1, wherein the first and second electrodes are elongated in a first direction, and wherein the conveyor unit is configured to move the carrier mesh in a second direction that is perpendicular to the first direction.

3. The system of any one of the previous claims, wherein the carrier mesh includes a frontside, wherein the first electrode is adjacent to the backside, wherein the second electrode is adjacent to the frontside.

4. The system of any one of the previous claims, wherein the second electrode is at least partially encased in a dielectric (408), the dielectric extending at least in a direction towards the first electrode.

5. The system of any one of the previous claims, wherein the second electrode is shaped as a solid or hollow cylinder, wherein in particular the dielectric and the carrier mesh are positioned such that the dielectric is in contact with the frontside of the carrier mesh.

6. The system of any one of the previous claims, wherein the dielectric has a thickness of at least 0.2 cm, in particular a thickness of 0.2 cm to 10.0 cm, in particular of 1 cm to 5 cm, preferably 2.0 cm to 3.0 cm.

7. The system of any one of the previous claims, wherein the dielectric comprises plastic or rubber, in particular hard rubber.

8. The system of any one of the preceding claims, wherein, the dielectric has a dielectric constant of at least 2.0, preferably higher, e.g., at least 2.2, or at least 2.5, or at least 3.0.

9. The system of any one of the previous claims, wherein the second electrode is configured to be rotatable about a longitudinal axis.

10. The system of any one of the preceding claims, wherein the system is configured to enable a user to manually adjust the speed of the carrier mesh moving through the air gap and/or wherein the control unit (114) is configured to automatically adjust the speed.

11. The system of any one of the preceding claims, wherein the control unit is configured to control the application of the dielectric barrier discharge to the backside of the carrier mesh at an energy density of at least 0.1 J/cm^2, in particular of at least 0.3 J/cm^2, in particular of at least 0.5 J/cm^2, and in particular between 0.5 J/cm^2 and 0.6 J/cm^2.

12. The system of any one of the preceding claims,

- wherein the system further comprises a user interface for manually adjusting a gap between the first electrode and the second electrode; and/or
- wherein the control unit is configured to automatically adjust the gap between the first electrode and the second electrode.

13. The system of claim 12, wherein the gap is adjusted such that a distance between the first electrode and the outer surface of the dielectric at least partially enchasing the second electrode is greater than 0 mm, in particular greater than 15 mm, in particular greater than 30 mm, in particular greater than 40 mm, in particular between 40 mm and 80 mm.

14. The system of any one of the previous claims, wherein the first electrode and the carrier mesh are positioned such that a distance between the first electrode and a surface of the backside of the carrier mesh and the fiber portions protruding therefrom is below 10 mm, in particular below 5 mm, in particular between 0 mm and 3 mm.

15. The system of any one of the preceding claims, wherein the control unit is configured to control the dielectric barrier discharge device to continuously apply the dielectric barrier discharge to the backside for plasma-activating the backside.

16. The system of any one of the preceding claims, wherein the first electrode is a single wire or a set of two or more wires (602, 604).

17. The system of any one of the preceding claims 1-16, wherein the first electrode is a single conductive profile or a set of two or more conductive profiles (958), wherein a conductive profile is in particular a metal rod or metal bar.

18. The system of any one of the preceding claims, wherein the first electrode is a set of two or more conductive wires or profiles galvanically decoupled from each other.

19. The system of any one of the previous claims, further comprising:

- a fiber inserter (102) configured to receive the artificial turf carrier mesh (104) and artificial turf

fiber (106), and insert the artificial turf fiber into the carrier mesh.

20. The system of any one of the previous claims, wherein the system is an inline manufacturing facility for artificial turf.

21. The system of claim 20, wherein the fiber inserter (102) of claim 18, if present, the conveyor unit (108, 110, 107), the dielectric barrier discharge device (112) and the dispensing unit (116) are elements of the same manufacturing assembly line and are operatively coupled to each other.

22. The system of claim 21, wherein the operative coupling is implemented such that the carrier mesh comprising the inserted fibers is transported by the conveyor unit from the fiber inserter to the dielectric barrier discharge device for performing a plasma activation of the backside of the carrier mesh and at least some fiber portions of the inserted fibers protruding from the backside, and then transported to the dispensing unit configured to apply the backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

Amended claims in accordance with Rule 137(2) EPC.

1. A system (100) for manufacturing an artificial turf (136), comprising:

- a dielectric barrier discharge device (112) including a first electrode (402, 602, 604, 958) and a second electrode (404);
- a carrier mesh, wherein the carrier mesh includes a backside, and wherein the carrier mesh includes fibers integrated such that a portion of the fibers are exposed on the backside;
- a conveyor unit (108, 110, 107) configured for moving the carrier mesh (960) through an air gap (405) formed between the first electrode and the second electrode;
- a control unit (114) configured to control the dielectric barrier discharge device to apply a dielectric barrier discharge to the backside of the carrier mesh as the carrier mesh moves through the air gap for plasma-activating the backside; and
- a dispensing unit (116) configured to apply a backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

2. The system of claim 1, wherein the first and second electrodes are elongated in a first direction, and wherein the conveyor unit is configured to move the carrier mesh in a second direction that is perpendicular to the first direction.

3. The system of any one of the previous claims, wherein the carrier mesh includes a frontside, wherein the first electrode is adjacent to the backside, wherein the second electrode is adjacent to the frontside.

4. The system of any one of the previous claims, wherein the second electrode is at least partially encased in a dielectric (408), the dielectric extending at least in a direction towards the first electrode.

5. The system of any one of the previous claims, wherein the second electrode is shaped as a solid or hollow cylinder, wherein in particular the dielectric and the carrier mesh are positioned such that the dielectric is in contact with the frontside of the carrier mesh.

6. The system of any one of the previous claims, wherein the dielectric has a thickness of at least 0.2 cm, in particular a thickness of 0.2 cm to 10.0 cm, in particular of 1 cm to 5 cm, preferably 2.0 cm to 3.0 cm.

7. The system of any one of the previous claims, wherein the dielectric comprises plastic or rubber, in particular hard rubber.

8. The system of any one of the preceding claims, wherein, the dielectric has a dielectric constant of at least 2.0, preferably higher, e.g., at least 2.2, or at least 2.5, or at least 3.0.

9. The system of any one of the previous claims, wherein the second electrode is configured to be rotatable about a longitudinal axis.

10. The system of any one of the preceding claims, wherein the system is configured to enable a user to manually adjust the speed of the carrier mesh moving through the air gap and/or wherein the control unit (114) is configured to automatically adjust the speed.

11. The system of any one of the preceding claims, wherein the control unit is configured to control the application of the dielectric barrier discharge to the backside of the carrier mesh at an energy density of at least 0.1 J/cm^2, in particular of at least 0.3 J/cm^2, in particular of at least 0.5 J/cm^2, and in particular between 0.5 J/cm^2 and 0.6 J/cm^2.

12. The system of any one of the preceding claims,

- wherein the system further comprises a user interface for manually adjusting a gap between the first electrode and the second electrode; and/or
- wherein the control unit is configured to automatically adjust the gap between the first electrode and the second electrode.

13. The system of claim 12, wherein the gap is adjusted such that a distance between the first electrode and the outer surface of the dielectric at least partially enchasing the second electrode is greater than 0 mm, in particular greater than 15 mm, in particular greater than 30 mm, in particular greater than 40 mm, in particular between 40 mm and 80 mm.

14. The system of any one of the previous claims, wherein the first electrode and the carrier mesh are positioned such that a distance between the first electrode and a surface of the backside of the carrier mesh and the fiber portions protruding therefrom is below 10 mm, in particular below 5 mm, in particular between 0 mm and 3 mm.

15. The system of any one of the preceding claims, wherein the control unit is configured to control the dielectric barrier discharge device to continuously apply the dielectric barrier discharge to the backside for plasma-activating the backside.

16. The system of any one of the preceding claims, wherein the first electrode is a single wire or a set of two or more wires (602, 604).

17. The system of any one of the preceding claims 1-16, wherein the first electrode is a single conductive profile or a set of two or more conductive profiles (958), wherein a conductive profile is in particular a metal rod or metal bar.

18. The system of any one of the preceding claims, wherein the first electrode is a set of two or more conductive wires or profiles galvanically decoupled from each other.

19. The system of any one of the previous claims, further comprising:

    - a fiber inserter (102) configured to receive the artificial turf carrier mesh (104) and artificial turf fiber (106), and insert the artificial turf fiber into the carrier mesh.

20. The system of any one of the previous claims, wherein the system is an inline manufacturing facility for artificial turf.

21. The system of claim 20, wherein the fiber inserter (102) of claim 18, if present, the conveyor unit (108, 110, 107), the dielectric barrier discharge device (112) and the dispensing unit (116) are elements of the same manufacturing assembly line and are operatively coupled to each other.

22. The system of claim 21, wherein the operative coupling is implemented such that the carrier mesh comprising the inserted fibers is transported by the conveyor unit from the fiber inserter to the dielectric barrier discharge device for performing a plasma activation of the backside of the carrier mesh and at least some fiber portions of the inserted fibers protruding from the backside, and then transported to the dispensing unit configured to apply the backing layer to the plasma-activated backside of the carrier mesh for providing the artificial turf.

23. The system of any one of the previous claims, wherein the dielectric barrier discharge device is configured to generate a voltage field between the first electrode and the second electrode of at least 1 kV.

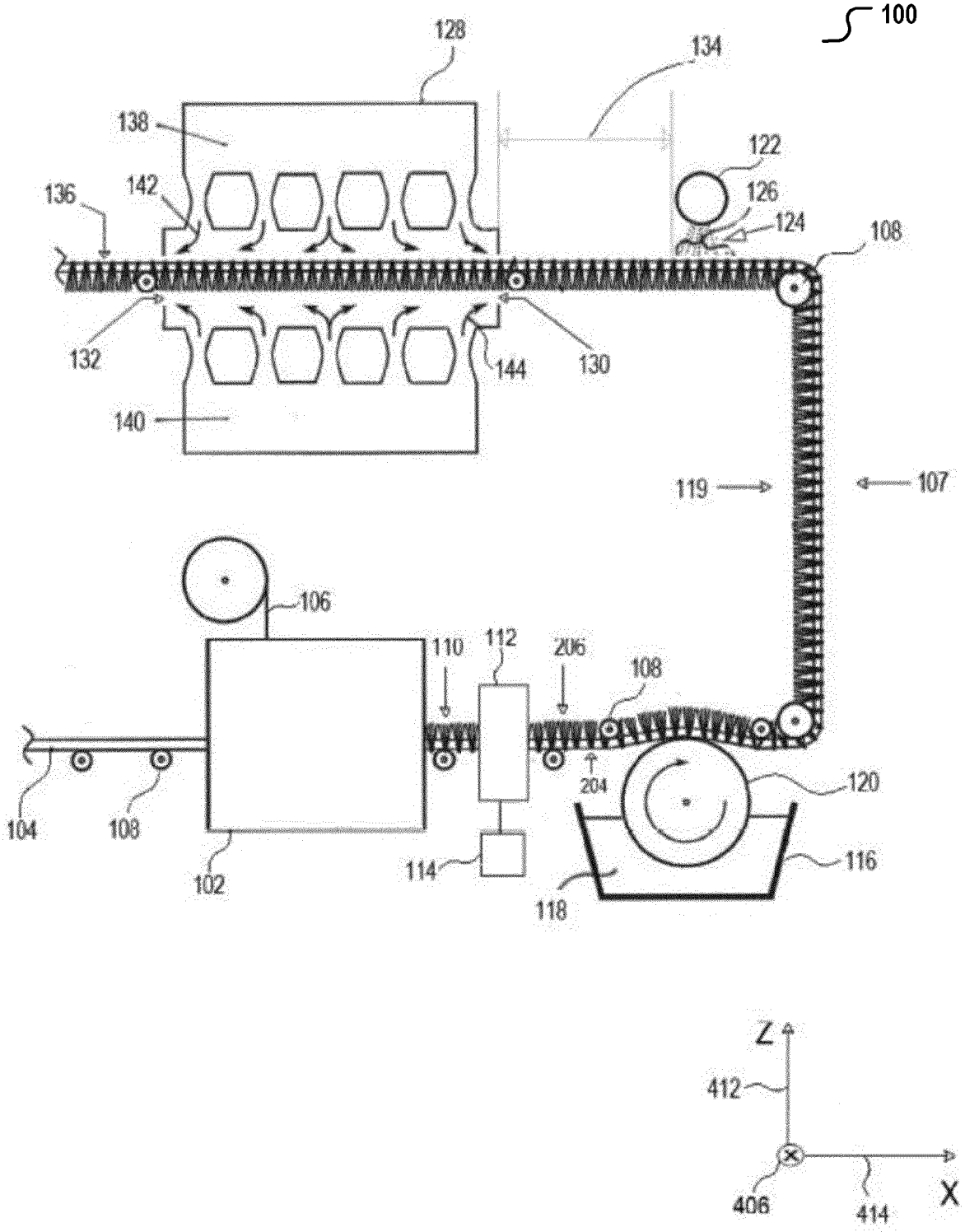
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Fig. 1

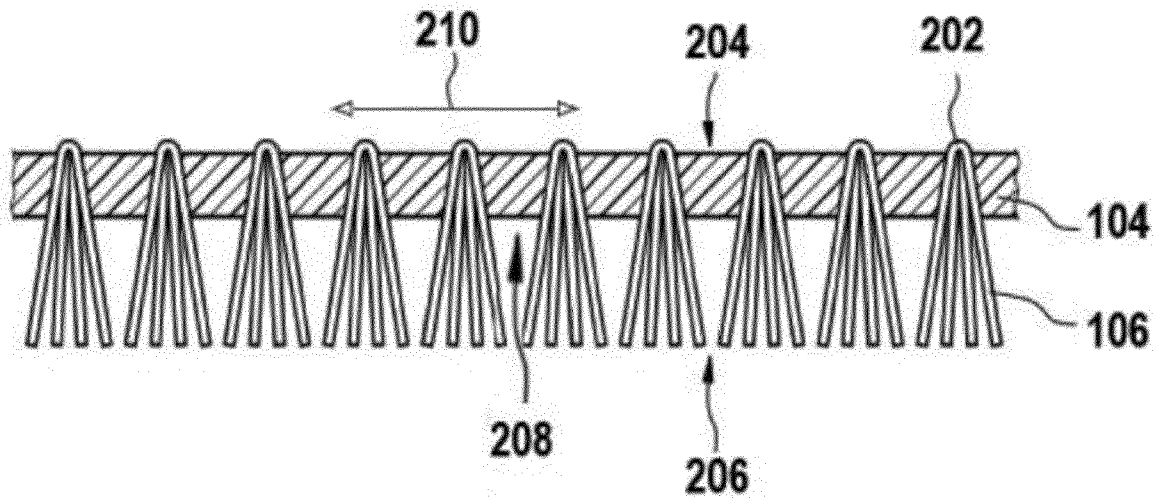

Fig. 2

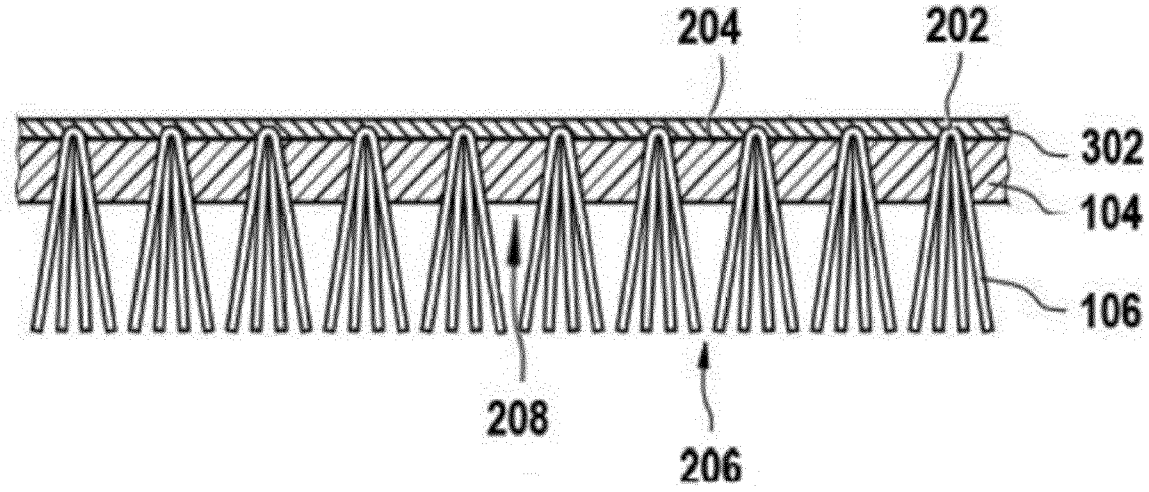

Fig. 3

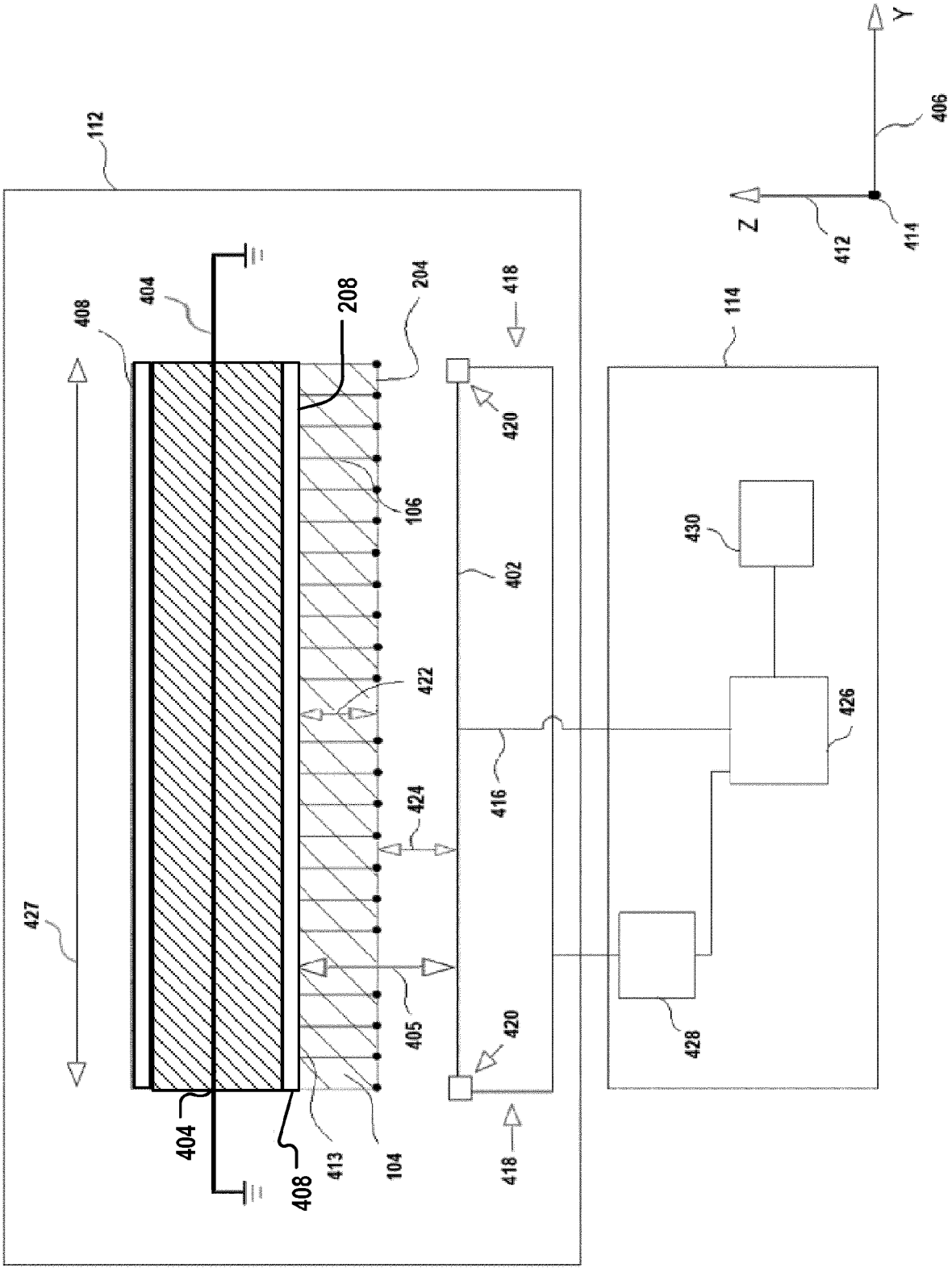
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Fig. 4

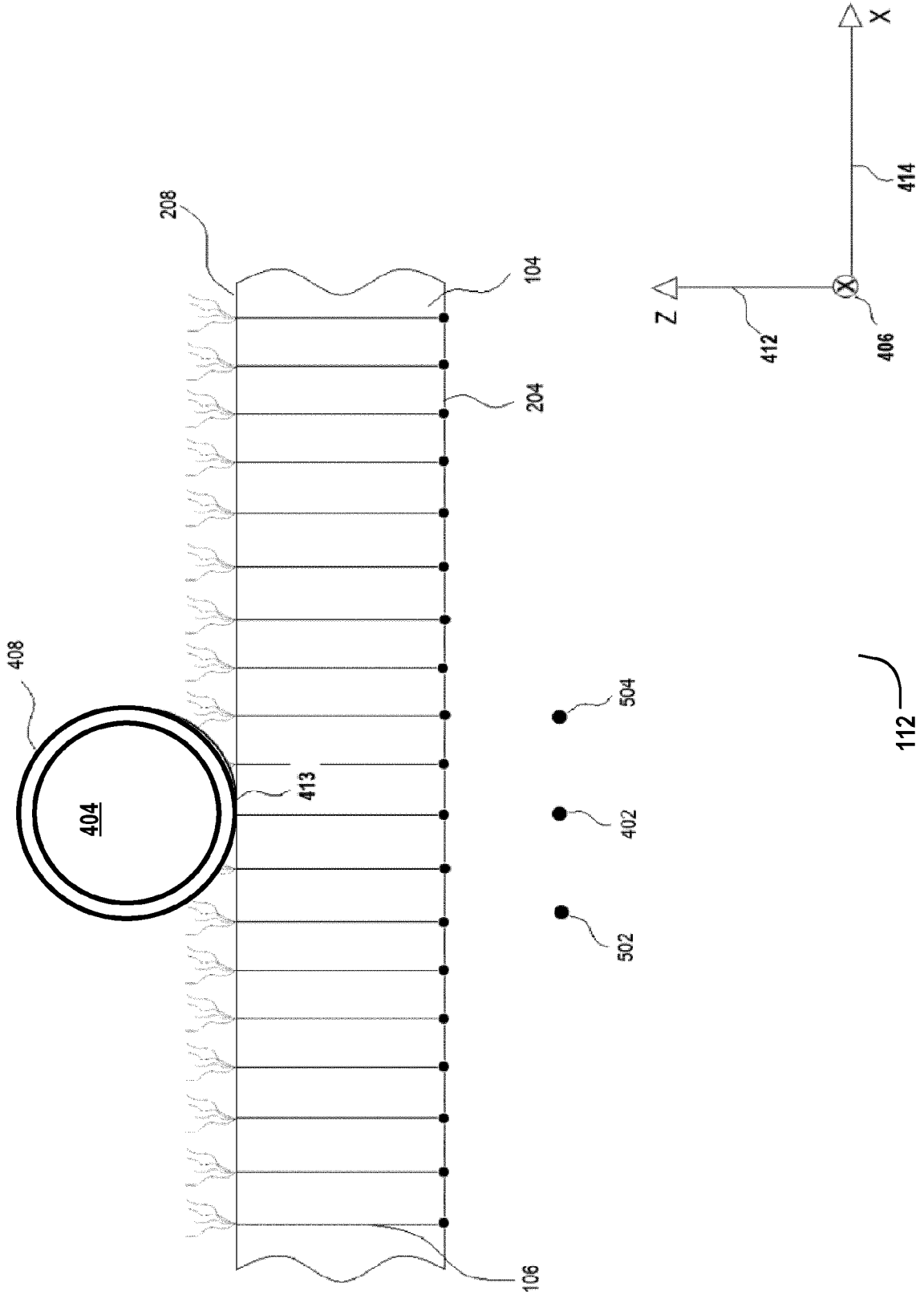

Fig. 5

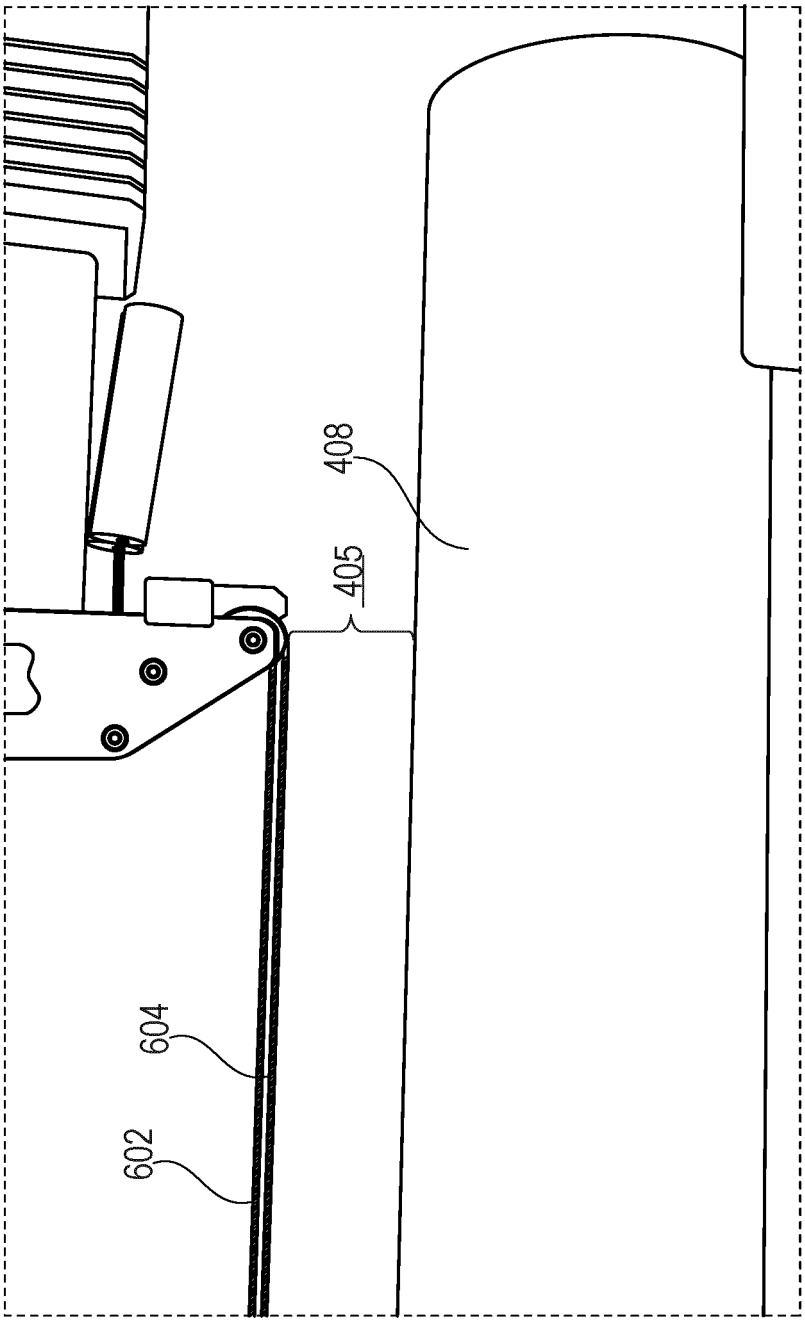

Fig. 6

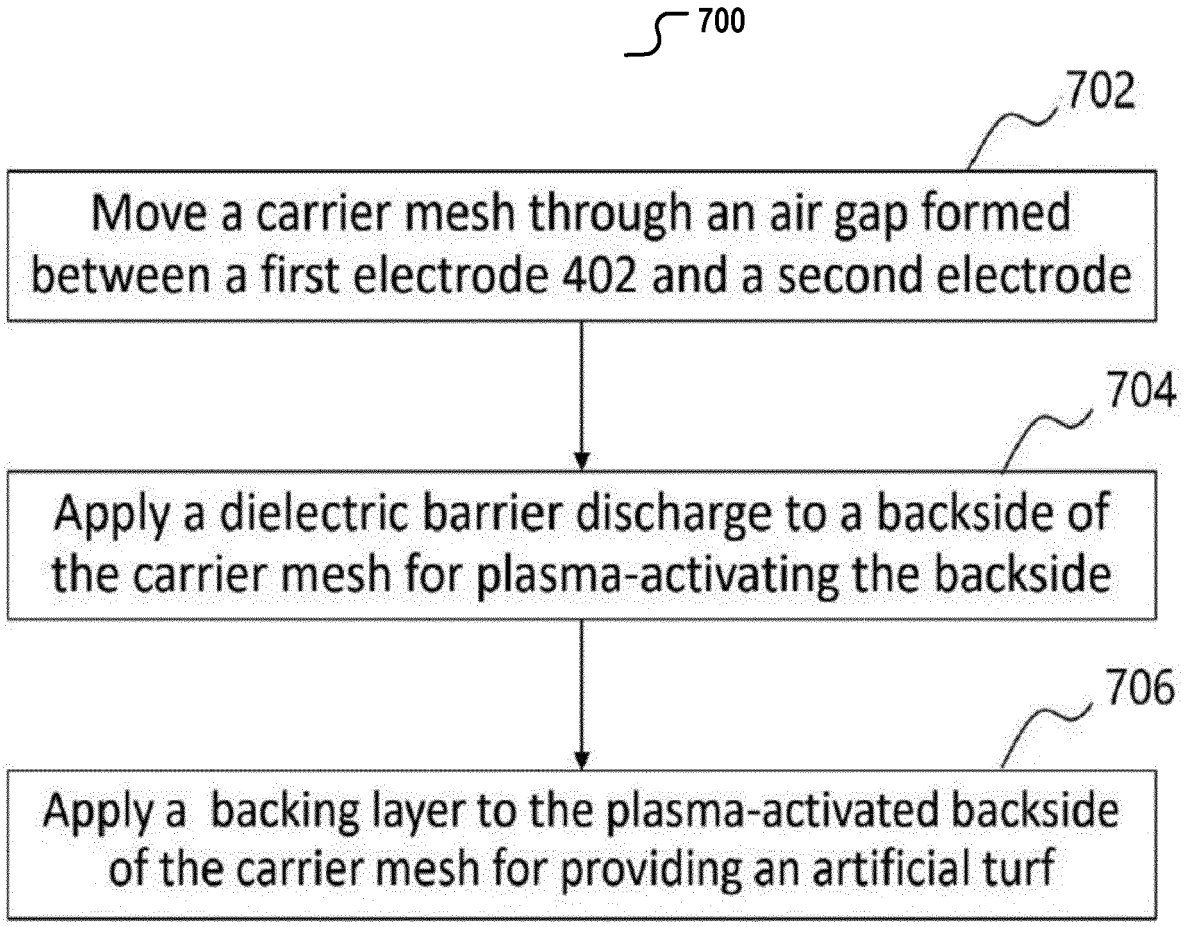
700
702
Move a carrier mesh through an air gap formed between a first electrode 402 and a second electrode
704
Apply a dielectric barrier discharge to a backside of the carrier mesh for plasma-activating the backside
706
Apply a backing layer to the plasma-activated backside of the carrier mesh for providing an artificial turf

Fig. 7

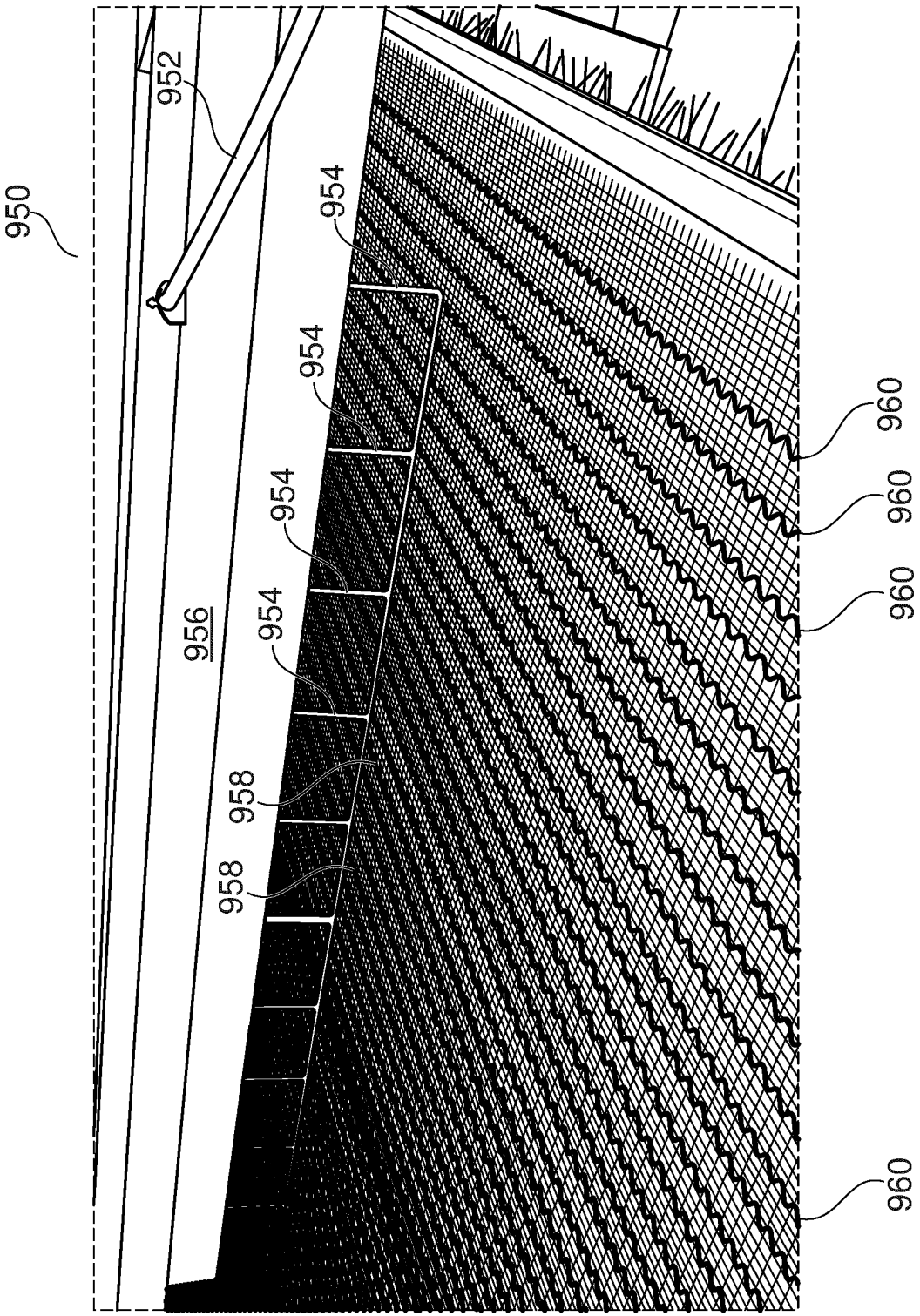

Fig. 8

	Applied power	Tufting	Transport speed m/min	Coating Temperature °C/°F	actual coating thickness g/m²2	Sample fiber type	bundle withdrawal force Sample 1	bundle withdrawal force Sample 2	bundle withdrawal force Sample 3	bundle withdrawal force Sample Ø	bundle withdrawal force % of Original	Standard deviation Samples 1-3 untreated	Standard deviation samples 1-3 plasma-treated
Turf 1	500 Watt	260 18/4	6	70/130	688	smooth	56	56	57	56			0.55
	0 Watt (control)	260 18/4	6	70/130	688	smooth	37	30	35	34		3.58	
	0 Watt (control)	260 18/4	6	70/130	688	smooth	36	41	33	37		3.60	
	500 Watt	260 18/4	6	70/130	688	smooth (after 14 days aging)	72	69	74	71	134		2.58
	0 Watt (control)	260 18/4	6	70/130	688	smooth (after 14 days aging)	47	43	35	41	121	6.17	
	0 Watt (control)	260 18/4	6	70/130	688	smooth (after 14 days aging)	46	39	45	43	116	3.84	
	500 Watt	260 18/4	6	70/130	688	smooth after 4 weeks (dry)	64	70	65	66			3.18
	0 Watt (control)	260 18/4	6	70/130	688	smooth after 4 weeks (dry)	34	51	31	39		10.87	
	0 Watt (control)	260 18/4	6	70/130	688	smooth after 4 weeks (dry)	46	35	45	42		5.80	
Turf 2	600 Watt	260 18/4	6	70/130	680	smooth	65	68	71	68			2.94
	0 Watt (control)	260 18/4	6	70/130	680	smooth	39	31	34	35		4.23	
	0 Watt (control)	260 18/4	6	70/130	680	smooth	40	49	28	39		10.53	
	600 Watt	260 18/4	6	70/130	680	smooth (after 14 days aging)	72	72	71	72	106		0.89
	0 Watt (control)	260 18/4	6	70/130	680	smooth (after 14 days aging)	42	50	42	45	132	4.83	
	0 Watt (control)	260 18/4	6	70/130	680	smooth (after 14 days aging)	35	52	31	39	100	11.27	
	600 Watt	260 18/4	6	70/130	680	smooth after 4 weeks (dry)	72	71	69	71			1.89
	0 Watt (control)	260 18/4	6	70/130	680	smooth after 4 weeks (dry)	40	52	40	44		6.84	
	0 Watt (control)	260 18/4	6	70/130	680	smooth after 4 weeks (dry)	50	36	32	39		9.69	
Turf 3	700 Watt	260 18/4	6	70/130	677	smooth	72	69	67	69			2.30
	0 Watt (control)	260 18/4	6	70/130	677	smooth	30	36	36	34		3.27	
	0 Watt (control)	260 18/4	6	70/130	677	smooth	38	38	30	35		4.59	
	700 Watt	260 18/4	6	70/130	677	smooth (after 14 days aging)	73	66	74	71	103		4.13
	0 Watt (control)	260 18/4	6	70/130	677	smooth (after 14 days aging)	40	44	39	41	121	2.91	
	0 Watt (control)	260 18/4	6	70/130	677	smooth (after 14 days aging)	39	27	47	38	106	10.05	
	700 Watt	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	68	73	72	71			2.46
	0 Watt (control)	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	52	49	48	50		2.37	
	0 Watt (control)	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	36	37	53	42		9.48	

Fig. 9A

Applied power	Tufting	Transport speed m/min	Coating Temperature °C/°F	actual coating thickness g/m²2	Sample fiber type	bundle withdrawal force Sample 1	bundle withdrawal force Sample 2	bundle withdrawal force Sample 3	bundle withdrawal force Sample Ø	bundle withdrawal force %of Original	Standardeviation Samples 1-3urtreated	Standard deviation samples 1-3 plasma-treated
700 Watt	260 18/4	6	70/130	677	smooth	68	70	70	69			1.13
0 Watt (control)	260 18/4	6	70/130	677	smooth	31	36	30	32		3.28	
0 Watt (control)	260 18/4	6	70/130	677	smooth	28	20	29	26		4.78	
700 Watt	260 18/4	6	70/130	677	smooth (after 14 days aging)	66	72	66	68	106		3.32
0 Watt (control)	260 18/4	6	70/130	677	smooth (after 14 days aging)	47	28	31	35	113	10.10	
0 Watt (control)	260 18/4	6	70/130	677	smooth (after 14 days aging)	32	39	31	34	123	4.21	
700 Watt	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	68	73	72	71			2.46
0 Watt (control)	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	54	49	46	50		4.34	
0 Watt (control)	260 18/4	6	70/130	677	smooth after 4 weeks (dry)	36	37	53	42		4.98	
700 Watt	238 15/8	6	60/130	680	texturizedurized	48	46	51	49			2.50
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized	32	34	29	32		2.41	
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized	39	31	34	35		3.93	
700 Watt	238 15/8	6	60/130	680	texturizedurized (after 14 days aging)	49	49	52	50	102		1.56
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized (after 14 days aging)	39	42	33	38	119	4.44	
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized (after 14 days aging)	31	35	25	30	86	4.91	
700 Watt	238 15/8	6	60/130	680	texturizedurized after 4 weeks (dry)	48	50	44	47			2.91
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized after 4 weeks (dry)	41	29	37	36		5.91	
0 Watt (control)	238 15/8	6	60/130	680	texturizedurized after 4 weeks (dry)	31	33	39	34		4.36	

Turf 4

Turf 5

Mean of standard deviation 5.87 2.32

Fig. 9B

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EUROPEAN SEARCH REPORT

Application Number
EP 23 19 8797

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H05H

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	8 March 2024	Clemente, Gianluigi

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