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(54) ARTIFICIAL TURF FIBERS COMPRISING POLYMER WASTE AND A COMPENSATORY POLYMER

(57) The invention relates to a method of manufacturing an artificial turf fiber (510). The method comprises: creating (302) a polymer mixture (100, 200) comprising molten plastic waste and a molten compensatory polymer (104), the plastic waste comprising one or more aged polymers (106), the compensatory polymer being an unaged polymer, the MFI of the compensatory polymer being at least four times higher than the MFI of the one or more aged polymers; extruding (304) the polymer mixture into a monofilament (406); and fabricating the artificial turf fiber from one or more of the monofilaments.

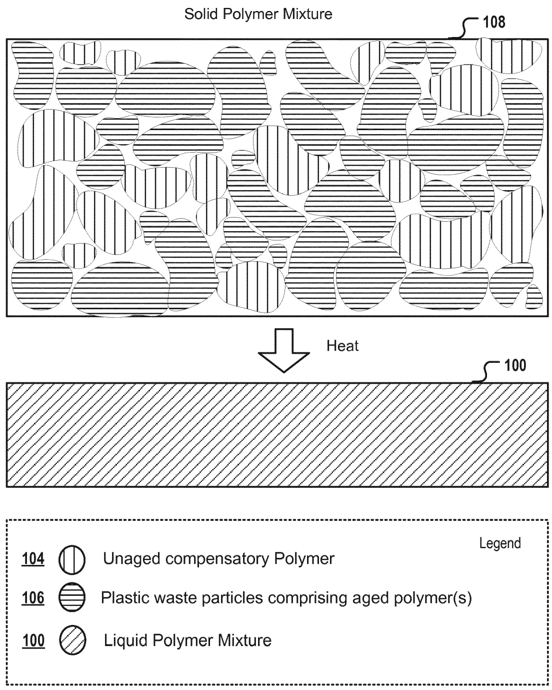


Fig. 1A

EP 3 604 675 A1

Description

Field of the invention

[0001] The invention relates to artificial turf and the production of artificial turf; artificial turf is also referred to as synthetic turf. The invention further relates to the production of artificial turf fibers, and in particular to artificial turf fibers that are partially made of plastic waste.

Background and related art

[0002] Artificial turf (or artificial grass) is a surface that is made of fibers and used to replace real grass. The structure of the artificial turf is designed such that the artificial turf resembles grass. Typically, artificial turf is used as a surface for sports such as soccer, football, rugby, tennis, and golf, and for playing or exercise fields. Furthermore, artificial turf is frequently used for landscaping applications. An advantage of using artificial turf is that it eliminates the need to care for a grass playing or landscaping surface, such as having to perform regular mowing, scarifying, fertilizing, and watering (and watering can be difficult due to logistics or regional restrictions on water usage). In other climatic zones, the regrowing of grass and reformation of a closed grass cover is slow compared with the rate of damaging the natural grass surface by playing and/or exercising on the field. Artificial turf may be manufactured using techniques for manufacturing carpets. For example, artificial turf fibers, which have the appearance of grass blades, may be tufted or otherwise integrated into a carrier. Often, artificial turf infill is placed between the artificial turf fibers. Artificial turf infill is a granular material that covers the lower portion of the artificial turf fibers.

[0003] Artificial turf fibers are typically made of polymers or polymer blends that have highly specific, defined mechanical properties. These properties ensure that the fibers can reliably recover from impact forces over a long period of time; have a desired optical appearance, elasticity, rigidity, and tensile strength; are easy to produce; and can be produced cost-effectively.

[0004] Today, more and more companies and sports clubs have become committed to sustainability. As a result, there have been several advances in using waste plastics for fabricating artificial turf fibers. For example, EP 2 161 374 B1 describes a method for producing an artificial turf for sports fields, garden design, and golf courses wherein the artificial turf fibers consist for the most part of polyethylene terephthalate (PET) and/or polybutylene terephthalate (PBT) from waste materials. The fibers are produced substantially as multicomponent fibers having a core-sheath configuration whereby the sheath plastic consists substantially of PET or PBT from waste materials or virgin PET or PBT, and whereby the core consists substantially of PET and/or PBT from waste materials.

[0005] A problem associated with many approaches to using plastic waste in the production of artificial turf fibers is that the available plastic waste is a "postconsumer" waste (i.e., a heterogeneous mixture of different types of plastics). Typically, the exact composition of postconsumer plastic waste is not known and varies over time. Hence, the mechanical and chemical properties of postconsumer plastic waste are typically not known and vary unpredictably. In many cases, this excludes the use of plastic waste as a polymer source for producing a new, high-quality artificial turf fiber. Sometimes, plastic waste is preprocessed in a complex manner, e.g., filtered, sorted, heated, or crystallized, in order to separate different types of polymers from each other. However, this preprocessing of waste is often highly time-consuming and expensive. What's more, frequently, different plastic types cannot be separated at all or cannot be separated into different polymer fractions that are sufficiently pure to be usable as an educt in an artificial turf fiber production process. Therefore, artificial turf fibers made from recycled plastic waste often require the plastic waste to be postindustrial waste rather than postconsumer waste, or they require a complex preprocessing of the postconsumer waste in order to separate the plastic waste into the different types of polymers to be used for manufacturing a new artificial turf fiber from old plastic waste.

Summary

[0006] The invention provides for an artificial turf fiber and a method of manufacturing an artificial turf fiber as specified in the independent claims. Embodiments are given in the dependent claims. Embodiments and examples described herein can be combined freely with each other if they are not mutually exclusive.

[0007] In one aspect, the invention provides for a method of manufacturing an artificial turf fiber. The method comprises creating a polymer mixture. The polymer mixture comprises molten plastic waste, which itself comprises one or more aged polymers, and a molten compensatory polymer. The compensatory polymer is an unaged polymer whose melt flow index (MFI) is at least four times lower than the MFI of the one or more aged polymers. The method comprises extruding the polymer mixture into a monofilament and fabricating the artificial turf fiber from one or more of the monofilaments.

[0008] Embodiments of the invention may allow fabricating artificial turf fibers being composed of plastic waste and a compensatory polymer.

[0009] The MFI (also referred to as melt flow rate - MFR) of a polymer is an indirect measure of the polymer's molecular weight and chain length. A high MFI corresponds to low molecular weight. The MFI is inversely proportional to viscosity of the melt on the conditions of the test. The MFI is very commonly used for specifying the molecular weight of polyolefins. The MFI can be measured for example in accordance with the ISO standard 1133-1. For example, polyethylene is measured at 190°C, and polypropylene at 230°C. In the context of injection molding, plastics engineers sometimes choose a polymer material with a desired MFI that is high enough that the molten polymer can be easily formed into the article intended but low enough that the mechanical strength of the final article will be sufficient for its use.

[0010] Hence, the compensatory polymer is a polymer whose average polymer chain length is greater than the average polymer chain length of the one or more aged polymers.

[0011] Applicant has surprisingly observed that combining a compensatory polymer having a particularly low MFI with one or more aged polymers may have the beneficial effect that the compensatory polymer "compensates" for adverse material properties (e.g., increased brittleness, decreased elasticity, and increased rigidity) caused by exposure of plastic waste to mechanical stress and sunlight. Applicant has observed that the exposure of plastic to mechanical stress and sunlight during use, or when being dumped as plastic waste in a waste dump or in the ocean, causes a reduction in the chain length of the plastic polymer and hence a molecular weight decrease and an increase in the MFI of the plastic polymer. Hence, Applicant has observed that aged polymers (in particular polymers contained in postconsumer plastic waste) are often characterized by a particularly high MFI, which corresponds to a low viscosity, low molecular weight, and short polymer chains. Applicant has further observed that combining the one or more aged polymers with a compensatory polymer having a particularly low MFI may allow for compensation for these adverse material properties of the aged polymer(s). The low MFI indicates that the compensatory polymer has a particularly high molecular weight and, correspondingly, has a particularly long polymer chain that is longer than the chain of a "typical" virgin polymer ("standard polymer") that would "normally" be used for manufacturing a particular artificial turf fiber. Typically, the compensatory polymer has a significantly higher molecular weight and a higher viscosity than the base polymer.

[0012] According to embodiments, the compensatory polymer is added to the polymer mixture such that the compensatory polymer and the one or more aged polymers (and, in some embodiments, an optional base polymer) form a liquid blend. The polymer blend is formed by heating the individual polymer components of the mixture above their respective melting points and mixing the molten polymers such that a homogeneous polymer blend is formed. Preferably, the compensatory polymer and the base polymer and/or the aged polymer(s) do not form chemical bonds (cross links) with each other. This may ease the manufacturing of recycled artificial turf fibers by only slightly modifying formulations that were developed for virgin polymers: Applicant has observed that the mere presence of a sufficient amount of the long-chain compensatory polymer in the liquid mixture is sufficient to compensate for the adverse material properties of the one or more aged polymers whose polymer chains have been shortened by UV radiation and other factors.

[0013] The compensatory polymer may be characterized by a particularly long polymer chain that is able to stabilize the extrusion product by promoting the creation of van der Waals bridges between the long polymer chains of the compensatory polymer; the "standard length" polymer chains of a base polymer, if any; and the short polymer chains of the one or more aged polymers. Hence, although the monofilament generated from the polymer mixture in an extrusion process may contain a high portion of short-chain, heterogeneous waste polymers, the mechanical properties of the monofilament may nevertheless be identical or similar to a monofilament that consists completely of virgin polymer(s). Hence, embodiments of the invention may allow manufacturing artificial turf fibers from plastic waste whereby the artificial turf fibers have basically the same quality and physical properties as artificial turf fibers made from virgin polymers.

[0014] According to embodiments, the polymer mixture is a polymer blend wherein the base polymer, if any; the compensatory polymer; and the one or more aged polymers and additives, if any, are homogeneously mixed.

[0015] According to embodiments, the polymer mixture further comprises a base polymer. The base polymer is an unaged polymer, e.g., an unaged polyethylene. In particular, the base polymer can be linear low-density polyethylene (LLDPE). Adding a base polymer may be beneficial, as the adding of a further unaged polymer may allow "fine tuning" of the fiber's physical properties, e.g., tensile strength, elasticity, rigidity, and surface roughness. Different types of sports fields and landscaping applications may have different requirements with respect to these properties. Adding a base polymer that is particularly suited to provide the desired mechanical properties of the manufactured fibers may hence facilitate the identification of a formulation for manufacturing artificial turf fibers from heterogeneous plastic waste of unknown origin.

[0016] According to embodiments, the base polymer has an MFI in the range of 2.0 to 5.0 g/10 min.

[0017] This may be advantageous, as this MFI range and corresponding molecular weight range have been observed to provide artificial turf fibers that are both elastic and sufficiently rigid to be re-erected after being trampled.

[0018] Applicant has observed as a further beneficial aspect that the combination of the one or more aged polymers and the compensatory polymer will typically yield a polymer with similar physical properties as the base polymer, provided the MFI of the compensatory polymer is at least four times lower than the MFI of the one or more aged polymers. This may be advantageous, as the formula that was hitherto used for manufacturing a particular type of artificial turf fiber from a virgin (base) polymer may need to be modified only slightly in order to allow the production of an artificial turf fiber of similar mechanical properties from heterogeneous polymer waste. For example, instead of a previously recommended amount of 100 parts of a virgin base polymer, only 60 parts of the virgin base polymer, 15% of the compensatory polymer, and about 25% of the one or more aged polymers may be used while keeping the amounts of all other additives unchanged.

[0019] According to embodiments, the polymer mixture comprises the base polymer in an amount of at least 5% by weight of the polymer mixture, e.g., in a range of 5 to 10% by weight of the polymer mixture. Optionally, the polymer mixture may further comprise a compatibilizer and/or one or more additives. The additives can be, for example, rheological additives, pigments, antimicrobial substances, or flame retardants.

[0020] According to embodiments, the compensatory polymer is polyethylene.

[0021] According to preferred embodiments, the compensatory polymer is high-density polyethylene (HDPE) or LDPE.

[0022] HDPE is a polyethylene thermoplastic made from petroleum. HDPE is known for its large strength-to-density ratio. The density of HDPE can range from 930 to 970 kg/m^3. Although the density of HDPE is only marginally higher than that of low-density polyethylene (LDPE), HDPE has little branching, giving it stronger intermolecular forces and more tensile strength than LDPE.

[0023] The use of HDPE having an MFI in the specified range may be particularly advantageous, as both the absence of branches as well as the long chain length significantly strengthen intermolecular forces between the polymers contained in the polymer blend, thereby compensating for the adverse properties of the short-chain aged polymers.

[0024] According to embodiments, the compensatory polymer has an MFI in the range of 0.6 to 1.2 g/10 min. This range has been observed to provide a particularly effective compensation for adverse properties of aged, UV-degraded, and fragmented aged polymer(s).

[0025] According to embodiments, the polymer mixture comprises the compensatory polymer in an amount of 5 to 15 % by weight of the polymer mixture. For example, the polymer mixture can comprise the compensatory polymer in an amount of 8 to 12% by weight of the polymer mixture.

[0026] According to embodiments, at least 1%, and preferably at least 10% - in some examples, more than 40% or 60% - by weight of the polymer mixture consists of the plastic waste. Typically, the plastic waste consists of the one or more aged polymers, so the amount of plastic waste in the polymer mixture is roughly identical to the amount of the one or more aged polymers in the polymer mixture.

[0027] According to embodiments, the one or more aged polymers, respectively, have an MFI in the range of 5.0 to 7.0 g/10 min.

[0028] According to embodiments, the plastic waste is a shredded, cut, crushed, minced, or plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste.

[0029] Applicant has observed that the compensatory polymer is able to compensate for the adverse properties of a large range of different UV-degraded and otherwise damaged aged polymers.

[0030] The one or more aged polymers can be, for example, polar polymers, apolar polymers, or mixtures thereof. The one or more aged polymers can comprise "waste" polyethylene (PE), "waste" polyamide (PA), "waste" polypropylene (PP), "waste" polyethylene-terephthalate (PET), "waste" polybutylene terephthalate (PBT), or a mixture of two or more of these polymer types.

[0031] PP is a thermoplastic polymer widely used in many different applications, including automotive components, containers, plastic parts, packaging and labeling, loudspeakers, stationery, and textiles. PP is rugged and resistant to different chemical solvents, acids, and bases. It is also used for producing low-cost artificial turf fibers that are particularly chemically robust.

[0032] PET is a plastic often used for manufacturing food-grade plastic, e.g., plastic bottles. It is also used for producing "bundling fibers" (i.e., a special type of fiber used for bundling two or more monofilaments into an artificial turf fiber). PET is particularly mechanically robust.

[0033] PA is a macromolecule with repeating units linked by amide bonds. Artificially made polyamides can be made through step-growth polymerization or solid-phase synthesis, yielding materials such as nylons, aramids, and sodium polyaspartate. Synthetic polyamides are commonly used in textiles, automotive applications, carpets, and sportswear because of their high durability and strength. PA is also used for manufacturing artificial turf fibers.

[0034] Some of the abovementioned materials, e.g., PA and PET, are not miscible with PE when heated together, e.g., in an extruder. As a consequence, plastic waste that consists of, comprises, or is contaminated with a PA or PET polymer may be a technical challenge, because apolar and polar polymers tend to form different, separate phases, and the resulting extrusion product tends to delaminate and break at the contact surface of the two different phases. According to embodiments, the polymer mixture comprises a compatibilizer (i.e., an amphiphilic substance that is adapted to emulsify at least small amounts of an aged, polar polymer into an apolar blend of other aged polymers and the compensatory polymer or that is adapted to emulsify at least small amounts of an apolar aged polymer into a polar blend of other aged polymers and the compensatory polymer). By adding a compatibilizer, it is ensured that plastic waste consisting of, comprising, or contaminated with PA, PET, or PBT can be used for generating high-quality artificial turf fibers. Hence, large amounts of heterogeneous postconsumer plastic waste may now be fully recycled and may be used for manufacturing new artificial turf fibers.

[0035] According to embodiments, the plastic waste comprises a mixture of two or more different types of aged polymers. For example, the plastic waste can be shredded plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste. The one or more aged polymers contained in the plastic waste can be an unknown combination of a plurality of different types of aged polymers. The heterogeneous waste plastic may comprise plastics made of many different types of polyolefin polymers; may comprise plastics with different degrees of oxidation and photo bleaching; may comprise an unknown mixture of polar and apolar polymers; and/or may comprise a mixture of plastics having strongly different melting temperatures. Postconsumer plastic waste is typically highly heterogeneous. Often, the composition of the plastic waste varies significantly over time, depending on the source from which the plastic waste is derived. Typically, the plastic waste is a shredded, cut, crushed, minced, ground, or otherwise dismembered mixture of plastic waste derived from one or more different sources. Embodiments of the invention may be advantageous, as it may be possible to also use heterogeneous waste plastic of unknown and varying composition for producing new artificial turf fibers.

[0036] According to embodiments, the plastic waste consists of or comprises ocean plastics.

[0037] This feature may be advantageous, as ocean plastic is an example of a highly oxidized, highly heterogeneous plastic waste source that comprises different types of polymers in different degrees of degradation and oxidation. Ocean plastic is commonly considered to be particularly difficult to recycle because of the heterogeneity and unpredictability of its composition.

[0038] According to embodiments, the plastic waste comprises used artificial turf fibers. This may be advantageous, as the polymers contained in used artificial turf fibers may have a higher probability of reflecting the mechanical properties desired when manufacturing new artificial turf fibers.

[0039] Current artificial turf systems are often highly complex products that may comprise a large number of different fiber types, and each fiber type may consist of one or more different polymer types. For example, an artificial turf could comprise face yarn fiber, which faithfully reproduces the look and feel of natural grass. These face yarn fibers could consist of a combination of PE and PA. In addition, the artificial turf could comprise thatch yarn fibers made of PP or a PP-based blend. In addition, or alternatively, the artificial turf may comprise a bundle fiber that is used for bundling together two or more monofilaments. The bundle fiber may be a PET fiber. It is not technically possible at this time to separate these different types of fibers, let alone the components of fibers consisting of a polymer blend, into the different fiber types or the individual pure polymer types. Typically, if an old artificial turf field is de-installed after a use time of 10, 20, or 30 years, the detailed composition of the field and its fibers is not known. Even if it were known, it would not be feasible to separate the different fibers and polymers contained in old artificial turf. Embodiments of the invention allow manufacturing high-quality artificial turf fibers that comprise significant portions of heterogeneous aged polymers derived from worn-out used artificial turfs. This may be advantageous, as artificial turf fields typically exhibit wear after five to 15 years. Mechanical damage from use and exposure to UV radiation, thermal cycling, interactions with chemicals, and various environmental conditions generate wear on artificial turf. It is therefore beneficial, both economically and environmentally, to use an existing worn artificial turf as a base for manufacturing a new artificial turf system. The manufacturing of the artificial turf fiber is preferably free of any preprocessing step for separating the different aged polymers contained in the plastic waste used to provide the polymer mixture.

[0040] For example, the mixture of different types of artificial turf fibers can be used as the source of the one or more aged polymers. The mixture of the different artificial turf fibers can comprise face yarn fibers, thatch yarn fibers, and/or bundling fibers. The face yarn fibers can be made, for example, from PE, PP, or PE/PA fibers. The thatch yarn fibers can be made of PA or PE/PA. The bundling fibers can be made of PET. In one example, the mixture of different types of artificial turf fibers used as the aged polymer material from which the one or more aged polymers are derived comprises 1 to 8% PET, in particular 2 to 5% PET. The rest can be PE or a combination of at least 70% PE in combination with PA and/or PP.

[0041] As a further beneficial aspect, the use of "old" artificial turf fiber may reduce the heterogeneity of the plastic waste (artificial turf fiber waste tends to be less heterogeneous than ocean plastic waste). This may enable providing a polymer mixture that does not comprise a base polymer and rather consists completely of the one or more aged polymers derived from the waste artificial turf fibers and the compensatory polymers and some optional additives. In some examples, the one or more aged polymers derived from old artificial turf fibers basically consist of waste PE that comprises some traces of waste PA and/or waste PET. The use of old artificial turf fiber as the plastic waste may provide for a polymer mixture that comprises no, or only small, amounts of polar aged polymers. In this case, the maximum allowed aged polymer content in the polymer mixture is particularly high.

[0042] According to some embodiments, the plastic waste comprises a mixture of different types of used artificial turf fibers. For example, the plastic waste may comprise PE-based face yarn fibers, PA-based thatch yarn fibers, and PET-based bundling fibers used to bundle a plurality of face yarn fibers together.

[0043] According to embodiments, the polymer mixture comprises light stabilizers in an amount of at least 0.6% by weight of the polymer mixture, preferably in the range of 0.7% to 1.2% by weight of the polymer mixture. For example, the base polymer, if any; the compensatory polymer; and the plastic waste comprising the one or more aged polymers and the light stabilizers may be mixed and used for providing the polymer mixture. The light stabilizers are added in such an amount that the final concentration of the light stabilizers in the polymer mixture is in the above-specified range. For example, it can be assumed that the concentration of light stabilizers in plastic that was in use for more than five years or that was stored in a garbage dump for more than five years is basically zero or close to zero. Hence, in order to reach the desired light stabilizer range, the amount of light stabilizer required can be computed based on the assumption that the one or more aged polymers are free of a light stabilizer. Light stabilizers - e.g., hindered amine light stabilizers (HALS) - tend to migrate and leave polymer materials after several years of use. Hence, even in cases in which the aged polymers in their original products comprised some light stabilizers, embodiments of the invention provide for a polymer mixture that, in addition, comprises an amount of light stabilizer that is computed based on the assumption that the one or more aged polymers are free of a light stabilizer.

[0044] According to embodiments, the light stabilizer is HALS.

[0045] According to preferred embodiments, the amount of the light stabilizers, e.g., the HALS, in the liquid polymer mixture is 0.7% to 0.9% by weight of the polymer mixture.

[0046] According to embodiments, the polymer mixture is a liquid polymer blend.

[0047] The invention also relates to a method of manufacturing artificial turf. The method comprises incorporating a plurality of artificial turf fibers manufactured according to any one of the embodiments and examples described herein into a carrier, e.g., a textile mesh.

[0048] In a further aspect, the invention relates to an artificial turf fiber manufactured according to the method of any one of the embodiments and examples described herein.

[0049] In a further aspect, the invention relates to an artificial turf fiber comprising at least one monofilament. Each of the at least one monofilament comprises one or more aged polymers and a compensatory polymer. The compensatory polymer is an unaged polymer whose MFI is at least four times lower than the MFI of the one or more aged polymers.

[0050] According to embodiments, the polymer mixture further comprises a base polymer wherein the base polymer is an unaged polymer. The base polymer can be, for example, PE, in particular LLDPE.

[0051] The monofilament is an extruded product of a polymer mixture comprising the one or more aged polymers and the compensatory polymer. Optionally, the polymer mixture may further comprise a base polymer and/or additives.

[0052] According to embodiments, the at least one monofilament has a core-cladding structure. The core is made of a core polymer mixture, and the cladding is made of a cladding polymer. The core polymer mixture comprises the one or more aged polymers and the compensatory polymer. Optionally, the core polymer mixture may, in addition, comprise a base polymer.

[0053] According to preferred embodiments, the cladding polymer consists basically of a polymer that is identical to either the compensatory polymer contained in the core or to a blend of a compensatory polymer and a base polymer, whereby the ratio of the compensatory polymer and the base polymer in the cladding is identical to the ratio of the compensatory polymer and the base polymer in the core.

[0054] In a further aspect, the invention relates to an artificial turf comprising a carrier and an artificial turf fiber, according to any one of the embodiments and examples described herein. The fiber is incorporated into the carrier.

[0055] According to embodiments, the one or more aged polymers and the compensatory polymer are apolar polymers, e.g., a type of PE. Preferably, the base polymer, if any, also is an apolar polymer. In some embodiments, at least one of the one or more aged polymers is a polar polymer, e.g., "waste" PA.

[0056] A "blend" or "polymer blend" as used herein is a mixture of two or more different polymers and optional additives. A blend can be generated by a mixer or blender or a component of an extrusion machine that performs the mixing. According to one embodiment, the blend is a single-phase system. In other embodiments, the blend is a multiphase system.

[0057] A "thread polymer" is understood here as any polymer that can be used to form threadlike regions within another polymer or polymer mixture in the presence of a compatibilizer if the other polymer or polymer mixture is extruded into a monofilament. Optionally, the monofilament can be stretched and the threadlike regions can be further elongated in the stretching process. The thread polymer is chosen to exhibit preferably a high bending stiffness after being stretched into threadlike regions as described herein. The bending stiffness may be sufficiently high that no further means are needed to provide a desired level of resilience to an artificial turf fiber manufactured from the monofilament. In solid form, the thread polymer may differ from the base polymer with regard to rigidity and/or density. The thread polymer is immiscible with the base polymer. Preferably, the thread polymer is a polar polymer.

[0058] The term "polymer bead" or "bead" may refer to a localized piece, such as a droplet, of a polymer that is immiscible with another polymer. The polymer beads may in some instances be round, spherical, or oval-shaped, but they may also be irregularly shaped. In some instances, the polymer beads will be approximately 0.1 to 3 micrometers, and preferably 1 to 2 micrometers, in diameter. In other examples, the polymer beads will be larger. They may, for instance, have a diameter of up to 50 micrometers.

[0059] The term "ocean plastics," as used herein, are plastics collected from the ocean. Typically, ocean plastics are a highly heterogeneous, strongly oxidized plastic mass. This mass can comprise basically any type of plastic product and its respective polymers. For example, ocean plastics can comprise plastic bags, plastic straws, old car tires, discarded fishing nets, plastic bottles, and/or other types of plastic waste.

[0060] The expression "[A] basically consists of [B]" as used herein means that at least 95% of the substance composition A consists of substance B. The substance composition may in addition comprise one or more additives, such as pigments, light stabilizers, biocides, flame retardants, and the like.

[0061] A "compatibilizer" as used herein is any substance that is capable of emulsifying a polymer that is immiscible with other polymers of a polymer mixture. For example, a compatibilizer can be an amphiphilic substance that comprises a polar and an apolar portion and that can emulsify a polar polymer in the form of droplets or beads within an apolar polymer blend, or can emulsify an apolar polymer in the form of droplets or beads within a polar polymer blend.

[0062] A "polymer" as used herein is preferably a polyolefin.

[0063] An "aged polymer" as used herein is an aged polymer, or polymer mixture derived from and/or contained in plastic products, that was subjected to aging, in particular UV-induced aging and decay. Typically, aged polymers are contained in waste plastics and are free of light stabilizers or comprise a significantly lower concentration of light stabilizers (e.g., HALS) than polymers contained in unaged plastic products do. For example, an unaged artificial turf fiber polymer typically comprises at least 0.7% by weight HALS, e.g., 0.7 to 0.9% HALS. After five years of exposing the fiber to sun, rain, and mechanical wear, the same fiber may comprise less than 0.3% HALS, and after some more years, the HALS content of an "aged polymer" will typically fall below 0.1%. Aged polymers are often strongly oxidized and/or have a smaller main chain length and side chain length than the unaged polymers from which they derive. According to preferred embodiments, the aged polymer(s) used for creating the polymer mixture have an MFI of below 1.5 g/10 min, in particular in the range of 0.6 to 1.2 g/10 min. Preferably, the one or more aged polymers are not extracted as individual polymer types from the plastic waste and are not added as separate polymers to the polymer mixture. The polymer waste is not preprocessed for separation of its individual aged polymer components. Rather, the aged polymer(s) used for creating the polymer mixture are added to the polymer mixture in the form of heterogeneous plastic waste. The plastic waste can be a mix of shredded and optionally aggregated plastic particles from different sources. Each piece of plastic waste can be made of a polymer of a particular type or can be made of a polymer blend. The plastic waste can be postindustrial and/or postconsumer plastic waste. According to embodiments, an aged polymer is a polymer exposed to sunlight and/or water for at least one year, e.g., polymers derived from outdoor products that have been in use for at least one year or polymers derived from plastic waste collected from the ocean, landfills, or other sources of waste. In some embodiments, an aged polymer is a polymer having been subject to sunlight for at least one year, preferably at least five years, and containing less than 0.3% HALS, in particular less than 0.1% HALS.

[0064] In cases in which the plastic waste comprises two or more different aged polymers, it is possible that some of the aged polymers are polar while other aged polymers are apolar and that, therefore, the aged polymers form different phases. Even in cases in which the multiple different aged polymers are all polar or are all apolar, the aged polymers may have different melting temperatures and may hence melt at different times when heated in the extruder, thereby at least temporarily forming a polymer mixture with different phases or regions basically consisting of different ones of the aged polymers. Preferably, all components of the polymer mixture are heated and optionally mixed (e.g., stirred, shaken, or otherwise intermixed) until all or most of the aged polymers form a homogeneous liquid polymer blend with each other and with the compensatory polymer (and with the base polymer, if any). Then, the liquid homogeneous polymer mixture is extruded into the monofilament. For many embodiments, the time interval between melting the aged polymer and the compensatory polymer (and the base polymer, if any) and performing the extrusion of the molten polymer mixture is shorter than five minutes, and preferably shorter than two minutes, and in particular shorter than one minute.

[0065] An "unaged polymer" (or "newly synthesized polymer", "newly produced polymer" or "virgin polymer") as used herein is any polymer that has not been in use as a component of a product. For example, an unaged polymer can be a polymer sold as a raw material to the polymer and plastic processing industry. In addition, or alternatively, the unaged polymer can be a polymer that was already processed by the polymer and plastic processing industry (e.g., by adding additional substances such as additives and pigments to the unaged polymer) but was not yet in use as part of a product. Hence, the unaged polymer may in fact also be several years old, but - contrary to aged polymers - has not yet been exposed to sunlight, rain, or mechanical stress, or has been exposed to said factors for less than one year and preferably for less than six months.

[0066] A "light stabilizer" as used herein is any substance that protects a plastic product from light-induced - in particular UV-induced - decay.

[0067] A "base polymer" can be any unaged polymer that has some desired properties with respect to the product to be generated. For example, the base polymer can be a particular type of PE, PA, or a mixture thereof. The base polymer can already comprise some additives, e.g., some rheological additives. The function of the base polymer may be to fine-tune the physical properties of the extruded monofilament and of the artificial turf fiber generated therefrom.

[0068] A "masterbatch" as used herein is a solid or liquid additive for plastic used for coloring plastics (color masterbatch) or imparting other properties to plastics (additive masterbatch). A masterbatch is a concentrated mixture of pigments and/or additives encapsulated during a heat process into a carrier resin, which is then cooled and cut into a granular shape. A masterbatch allows the processor to color raw polymer economically during the plastics manufacturing process. The alternatives to using masterbatches are buying a fully compounded material (which may be more expensive and less open to, for instance, color variability of the product) or compounding from raw materials on-site (which is prone to issues with achieving full dispersion of the colorants and additives, and with preparing more material than is needed for the production run). As masterbatches are already premixed compositions, their use alleviates issues with the additive or colorant clumping or with insufficient dispersion. The concentration of the additive in the masterbatch is much higher than in the end-use polymer, but the additive is already properly dispersed in the host resin. In a way, their use is similar to uses of ferroalloys for adding alloying elements to steels. According to embodiments, the masterbatches can be fairly highly concentrated (in comparison with the target composition) with high "letdown ratios"; e.g., one 25-kilogram bag can be used for one ton of the polymer mixture. The relatively diluted nature of masterbatches (in comparison with the raw additives) allows higher accuracy when dosing small amounts of expensive components. The compact nature of the grains of solid masterbatches eliminates problems with dust that is otherwise inherent in fine-grained solid additives. Solid masterbatches are also solvent-free; therefore, they tend to have a longer shelf life, as the solvent won't evaporate over time. The masterbatch usually contains 40 to 65% of the additive, but the range can be much wider, e.g., 15 to 80%. The carrier material of the masterbatch can be based on a wax (universal carrier) or on a specific polymer identical or compatible with the compensatory polymer used (polymer-specific). The carrier of the masterbatch can be referred to as the "base polymer" (also defined above).

[0069] A "core polymer" as used herein is a polymer or polymer blend used to form the core of a monofilament of the core-cladding type generated in a co-extrusion process.

[0070] A "cladding polymer" as used herein is a polymer or polymer blend used to form the cladding of a monofilament of the core-cladding type generated in a co-extrusion process.

[0071] According to some embodiments, the expression the ratio of the melt flow index of the compensatory polymer and that of the one or more aged polymers is determined by comparing the melt flow index of the pure compensatory polymer (derived empirically or derived from literature) with the derived melt flow index of the polymer blend of the aged polymers the plastic waste is composed of. For example, the melt flow index of the blend of the aged polymers can be obtained in a preprocessing step empirically by melting a sample of the plastic waste for generating a blend of two or more aged polymers, and by determining the melt flow index of this polymer blend.

Brief description of the drawings

[0072] In 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 the creation of a first and a second polymer mixture;
- Fig. 2 shows the creation of a third polymer mixture;
- Fig. 3 shows a flowchart that illustrates an example of a method of manufacturing an artificial turf fiber;
- Fig. 4 illustrates the extrusion of the polymer mixture into a monofilament;
- Fig. 5 shows the integration of artificial turf fibers into a carrier;
- Fig. 6A illustrates the effect of stretching the monofilament;
- Fig. 6B shows an electron microscope picture of a cross section of a stretched monofilament;
- Fig. 7 shows three cross sections of artificial turf fibers having a core-cladding structure; and
- Fig. 8 shows an extrusion head for co-extruding two polymer masses.

Detailed Description

[0073] Like-numbered elements in these figures are either equivalent elements or perform the same function. Elements that have been discussed previously will not necessarily be discussed in later figures if the function is equivalent.

[0074] **Fig. 1A** shows a cross section of a solid polymer mixture 108 of shredded pieces of plastic waste respectively consisting of one or more aged polymers 106 and granules of an unaged compensatory polymer 104. Optionally, the mixture 108 may comprise additives such as pigments, flame retardants, and light stabilizers (not shown). The solid polymer mixture 108 depicted in this figure 1A is free of a base polymer. The polymer mixture 108 can be generated, e.g., in a container in an extrusion machine, whereby the container preferably comprises heating elements and a stirrer or a screw or other means adapted to create a liquid, homogeneously mixed polymer blend 100, also referred to as polymer mixture 100. The polymer mixture depicted in figure 1A is a one-phase system.

[0075] Often, the composition of the one or more aged polymers is not known and/or varies over time. For example, the composition of the aged polymer(s) may vary between different product batches of the old artificial turf fibers used as the plastic waste. After 20 years of use of an artificial turf field, there is often no information available regarding the detailed composition of the old artificial turf system.

[0076] The mixture 100 can be created, e.g., by adding shredded plastic waste particles, the compensatory polymer 104, and some optional additives into an extruder and heating the components for performing the extrusion of the polymer mixture into a monofilament. The polymer mixture can be, for example, formed immediately before and during the extrusion process by heating the components of the polymer mixture. The melting temperature used during extrusions is dependent upon the type of plastic waste and compensatory polymer that is used. Typically, the melting temperature is between 230°C and 280°C.

[0077] The polymer mixture 100 can comprise two or more different types of aged polymers. The exact composition of the plastic waste used for creating the polymer mixture is typically not known. In fact, the plastic waste can be postconsumer waste whose polymer composition and/or degree of oxidation and decay vary greatly between different aged polymer batches. For example, the aged polymers may be a mixture of two or more different polymers, such as waste PE, PA, PP, PET, and/or PBT. In some embodiments, the plastic waste that is used for creating the polymer mixture is a heterogeneous plastic waste. The heterogeneous plastic waste can comprise, for example, old PET bottles, old artificial turf fibers, ocean plastic, plastic debris collected from biogas plants, or combinations thereof. In the example depicted in figure 1A, all aged polymers and the compensatory polymer are mixable with each other and form a one-phase polymer mixture 100. In other examples (not shown), some of the one or more aged polymers may be immiscible with each other or with the compensatory polymer and may form beads. In this case, a compatibilizer is added in order to emulsify the immiscible aged polymers, as shown in figure 2.

[0078] Embodiments of the invention allow the recycling (instead of burning or down-cycling) of aged artificial grass fibers by using them for the production of new artificial grass fibers. To achieve this, new UV stabilizers (e.g., HALS) can be added to the polymer mixture to compensate for the loss of HALS over the years (HALS are damaged by oils and other additives over time or have migrated out of the fibers). After many years in the sun (especially when the HALS have already largely migrated away), the UV radiation has massively damaged and shortened the main and side chains of the polymer, with the result that the inner cohesion is missing in the polymer, and the old polymer is brittle and can no longer be used for new artificial turf fibers. By adding 5 to 15% new particularly long-chain polymers, e.g., HDPE polymer with an MFI of 0.6 to 1.2 g/10 min, this "short-chain effect" can be compensated for. Light stabilizers are added to the blend such that the amount of light stabilizers in the blend is preferably in the range of about 0.7 to 0.9% of the blend by weight. The resulting blend can be used to produce new high-quality artificial grass fibers.

[0079] According to one example, the polymer mixture 108 contains plastic from old, used artificial turf fibers. Optionally, plastic waste from other sources of aged plastic is added to the mixture 108. UV stabilizers are added to the solid polymer mixture 108 or alternatively to the liquid blend to compensate for the aging-induced depletion of the old plastic on UV stabilizers (especially HALS).

[0080] The polymer blend 100 preferably has 0.7 to 0.9% by weight HALS. According to one embodiment, about 5 to 15% by weight of the blend 100 consists of the compensatory polymer 104 (i.e., a long-chain polymer such as long-chain HDPE). The average chain length of the compensatory polymer is significantly greater than the average chain length of the one or more aged polymers, and preferably even greater than the polymer length typically used for new plastic. For example, the chain length of the compensatory polymer, expressed in terms of the MFI, is preferably in the range of 0.6 to 1.2 g/10 min, whereas the MFI of a "normal" new PE polymer for artificial turf fiber production is usually in the range of 3 to 5 g/10 min. The length of the chain of the compensatory polymer serves to compensate for the UV damage to the aged polymer(s), because after a few years in the sun, the main chains and side chains of the plastic are often so "shattered" that the MFI of the aged polymer is 5 to 7 g/10 min and the plastic waste is very brittle.

[0081] According to one embodiment (that does not use a base polymer), the solid polymer mixture 108 has the following components, wherein the amount of the components is specified as a percentage by weight of the polymer mixture 108 - and, correspondingly, as a percentage by weight of the polymer mixture 100:

- 5 to 15% compensatory polymer, e.g., HDPE with an MFI of 0.9 g/10 min
- 2% additives, e.g., pigments, flame retardants, rheological additives, and antimicrobial substances, etc.
- optional: less than 0.5% process aids, e.g., thermoplastic copolymers;
- remainder (i.e., greater than 82.5%) being plastic waste consisting of one or more aged polymers, e.g., a mixture of shredded artificial turf fibers from many different sports fields that may comprise old PE fibers and, optionally, other old fibers, e.g., PA, PP, or PET fibers

[0082] Embodiments of the invention may allow using basically any kind of homogeneous, as well as heterogeneous, plastic waste for manufacturing an artificial turf fiber of clearly defined mechanical and optical properties. The resulting artificial turf fiber has properties that are identical or highly similar to those of an artificial turf fiber that is made completely of unaged polymer material.

[0083] The issue of recycling plastic waste lies in separating all the materials that are used to create new products from the recycled polymers so that the product reproducibly and predictably has the desired mechanical or chemical properties. For that reason, it was historically much easier - and less expensive - to simply toss plastic waste into a landfill or "recycle" plastic waste by incineration. However, Applicant has observed that adding a compensatory polymer and preferably also additional light stabilizers may allow the creation of a polymer mixture and a respective monofilament and artificial turf fiber that comprise more than 50% by weight plastic waste without significantly reducing the quality of the artificial turf fiber. The plastic waste can be homogeneous or heterogeneous plastic waste. Hence, embodiments of the invention may allow recycling rather than down-cycling or incinerating large amounts of heterogeneous postindustrial and postconsumer plastic waste, and they may enable the creation of artificial turf fibers from recycled polymer material that are identical or highly similar to "conventional" artificial turf fibers made from virgin polymers. The fibers made partially from aged polymers are typically not significantly more expensive than their conventional fiber counterparts.

[0084] Typically, the plastic waste consists of the one or more aged polymers and some additives such as pigments, flame retardants, and fillers, or the like. Usually, only about 5% or less, e.g., less than 1% by weight, of the plastic waste consists of the additives; the rest consists of the one or more aged polymers. Hence, in many embodiments, the plastic waste consists basically of the one or more aged polymers. Accordingly, the polymer mixture can contain more than 50% by weight of the one or more aged polymers.

[0085] In some embodiments, the polymer mixture comprises at least 10% by weight of the one or more aged polymers. In some embodiments, the polymer mixture comprises at least 20% by weight of the one or more aged polymers. In some embodiments, the polymer mixture comprises at least 30% by weight of the one or more aged polymers. Preferably, the polymer mixture comprises less than 71% by weight of the one or more aged polymers, e.g., 20 to 50% by weight of the one or more aged polymers.

[0086] **Fig. 1B** shows a cross section of a solid mixture 140 of shredded pieces of plastic waste respectively consisting of one or more aged polymers 106 and granules of an unaged compensatory polymer 104. Optionally, the mixture 140 may comprise additives such as pigments, flame retardants, and light stabilizers (not shown). The solid polymer mixture 140 depicted in figure 1B also comprises a base polymer. The base polymer is an unaged polymer, e.g., PE, that can be used for homogeneously dispersing the additives, e.g., pigments, in the blend 150 and/or for specifically adapting the physical and mechanical properties of the polymer blend 150 and of the resulting extrusion product in accordance with requirements of the intended use case scenario for the artificial turf fiber. For example, the base polymer can be the polymer that was used for manufacturing a masterbatch.

[0087] The extrusion machine is fed with premixed granules of the compensatory polymer, shredded pieces of the plastic waste, and the masterbatch. Optionally, some process aids are added to the extrusion machine and are mixed with the other components of the mixture 140. The final mixing then gets done in the screw and extrusion part of the machine, whereby the solid mixture 140 is heated above the melting temperature of all polymer components of the mixture 140, thereby providing the homogeneously mixed polymer mixture 150.

[0088] The polymer mixture 150 can be generated, for example, in a container in an extrusion machine as described with respect to the mixture 100. In some embodiments, the masterbatch can be added directly to the machine's screw as a free-flowing solid or, in the case of a liquid masterbatch, with, for example, a peristaltic pump. Such use of liquid masterbatches allows highly accurate dosing and quick changes of color between machine runs.

[0089] According to one example, the solid polymer mixture 140 has the following components, wherein the amount of the components is specified as a percentage by weight of the polymer mixture 140 and, correspondingly, as a percentage by weight of the polymer mixture 150:

- 8 to 10% masterbatch granules (consisting of an unaged base polymer, e.g., LLDPE with an MFI of 4.0 g/10 min, and additives that are homogeneously dispersed in the base polymer, e.g., pigments, flame retardants, rheological additives, and antimicrobial substances)
- 5 to 15% compensatory polymer, e.g., HDPE with an MFI of 0.9 g/10 min
- optional: less than 0.5% process aids, e.g., thermoplastic copolymers;
- remainder (that is, greater than 82.5%) being plastic waste consisting of one or more aged polymers, e.g., a mixture of shredded artificial turf fibers from many different sports fields that may contain old PE fibers and, optionally, other old fibers, e.g., PA, PP, or PET fibers

[0090] **Fig. 2** shows a cross section of a polymer mixture 200 that was created by heating a solid mixture of shredded pieces of plastic waste comprising one or more aged polymers 106, a compensatory polymer 104 - e.g., apolar HDPE - and a compatibilizer 204. The mixture may optionally also comprise a base polymer, e.g., an unaged LLDPE. In the example depicted in figure 2, some of the aged polymers were miscible with the compensatory polymer and the base polymer, if any, and form the polymer blend 100. At least one other aged polymer, e.g., PA or PET, is not miscible with the compensatory polymer (nor with the base polymer, if any). In this case, the adding of the compatibilizer ensures that the immiscible aged polymers are emulsified and form beadlike structures that are coated by the compatibilizer. The polymer blend 100, the compatibilizer 204 and the immiscible aged polymer acting as a thread polymer (defined above), each form a respective phase. Hence, the polymer blend 200 is a three-phase system.

[0091] In some embodiments, the solid polymer mixture 140 also comprises unaged polymer granules of a comparatively rigid polymer, e.g., PA granules. In this case, the thread polymer 202 consists of an unaged, rigid polymer rather than an immiscible aged polymer. In some further embodiments, the unaged, rigid polymer, e.g., unaged PA, intermixes with the immiscible aged polymer and forms a thread polymer 202 that is a blend of the immiscible aged polymer and an unaged rigid polymer.

[0092] Adding a compatibilizer may be advantageous, as the exact composition of the plastic waste is typically not known, and aged polymers that are not miscible with the compensatory polymer or any other polymer in the mixture may cause the extruded monofilament to delaminate on the contact surface of the two immiscible polymer types. The compatibilizer may ensure that even if the plastic waste contains traces of an immiscible polymer, this will not result in the delamination of the monofilament created from the polymer mixture.

[0093] As a further beneficial aspect, the emulsified beads will form threadlike regions when extruded into a monofilament. In addition, the threadlike regions may be elongated in an optional stretching step. These threadlike regions improve the mechanical robustness and rigidity of the manufactured artificial turf fiber. Adding an unaged rigid polymer to the polymer mixture 140 may ensure that even if the plastic waste should basically be free of any rigid, immiscible aged polymer, at least a minimum amount of threadlike regions will be formed, because the unaged rigid polymer will be emulsified into beads and will be stretched during the extrusion process into threadlike regions that increase the rigidity of the monofilament.

[0094] Stretching the polymer beads into the threadlike regions may cause an increase in the size of the crystalline portions relative to the amorphous portions in the thread polymer. This may lead, for instance, to the thread polymer becoming more rigid than when it has an amorphous structure. This in turn may lead to an artificial turf with more rigidity and ability to spring back when pressed down. The stretching of the monofilament may also cause - in some cases - the compensatory polymer or other polymers in the mixture to have a larger portion of their structure become more crystalline. In a specific example of this, the thread polymer could be polyamide, and the stretching of the polyamide will cause an increase in the crystalline regions, making the polyamide stiffer. This is also true for other plastic polymers. The extrusion of an emulsion of a polymer mixture generated by the compatibilizer will result in the fabrication of a monofilament that has a particularly high rigidity. This occurs because the beads are deformed during the extrusion process into threadlike regions that are oriented along the direction of the extrusion process. If the resulting monofilament is bent down, e.g., by the ball or by the foot of a player, the threadlike regions generated by the thread polymer ensure that the fiber will soon recover and "re-erect" from the impact. The compatibilizer may ensure that the thread polymer and the other polymers will not delaminate. A further advantage may possibly be that the threadlike regions are concentrated in a central region of the monofilament during the extrusion process. Yet another advantage may be that the artificial turf fibers have improved long-term elasticity. This may reduce the required amount of both the maintenance of the artificial turf and the brushing of the fibers, because the fibers more naturally regain their shape and stand up after being used or trampled.

[0095] The polymer mixture 200 is a multiphase system comprising at least the molten polymer mixture 100 depicted and described with reference to figure 1A, the compatibilizer 204 and the thread polymer 202. The compatibilizer forms a third phase and prevents the separation of the polymer mixture 100 and the immiscible thread polymer 202 into two large separate volumes by surrounding and embedding beadlike volumes of the thread polymer within the polymer mixture 100. This embedding of a small volume of one phase within another phase is referred to herein as "emulsification." The compatibilizer 104 emulsifies the thread polymer 202 within the polymer mixture 100, thereby forming a polymer mixture 200.

[0096] According to embodiments, the threadlike regions have a diameter of less than 50 micrometers. According to embodiments, the threadlike regions have a diameter of less than 10 micrometers. Additionally, according to embodiments, the threadlike regions have a diameter of between 1 and 3 micrometers. Further, according to embodiments, the artificial turf fiber extends a predetermined length beyond the artificial turf backing, and therein, threadlike regions have a length of less than one-half the predetermined length. According to embodiments, the threadlike regions have a length of less than 2 mm. In addition, according to embodiments, the polymer mixture comprises 1 to 30%, in particular 5 to 20%, and especially 5 to 15%, by weight of the polymer mixture the thread polymer.

[0097] As described with respect to the embodiments depicted in figures 1A and 1B, the mixture 108 may optionally also comprise additives such as pigments, flame retardants, light stabilizers, etc. (not shown). The liquid polymer mixture 100 that forms a phase of the liquid polymer mixture 150 may optionally also comprise a base polymer.

[0098] The mixture 200 can be created by, for example, adding shredded plastic waste particles that comprise traces of an aged polymer that is not miscible with a compensatory polymer 104, the compensatory polymer 104 itself and some optional additives into an extruder and heating the components for performing the extrusion of the polymer mixture into a monofilament. The polymer mixture 200 can be created from the following components:

- 5 to 15% compensatory polymer, e.g., HDPE with an MFI of 0.9 g/10 min

- 2% additives, e.g., pigments, flame retardants, rheological additives, and antimicrobial substances, etc.
- optional: less than 0.5% process aids, e.g., thermoplastic copolymers;
- 5% compatibilizer
- remainder (that is, greater than 69.5%) being plastic waste (e.g., a mixture of shredded artificial turf fibers from many different sports fields) that consists of about 10% of polar, aged PA and about 90% of apolar aged PE

[0099] In some cases, the plastic waste comprises some aged polymers that are temporarily (due to melting temperature differences) or permanently (due to polarity differences) not miscible with the base polymer and the compensatory polymer. This may be a technical problem, as the compensatory polymer (and/or the base polymer of the masterbatch) and the immiscible aged polymer may separate in the machine's hopper. This may be prevented by adding a compatibilizer, an amphiphilic substance that emulsifies the immiscible aged polymer(s), if any, with the other components of the polymer mixture. Adding a compatibilizer may even prevent the separation of temporarily immiscible polymers, as the amphiphilic substance generally eases the intermixing of different polymer components in the blend and hence facilitates and accelerates the homogeneous distribution of heat in the polymer mixture.

[0100] The compatibilizer 204 is preferably an amphiphilic substance.

[0101] The compatibilizer can be, for example, any one of the following: a maleic acid grafted on polyethylene or polyamide; a maleic anhydride grafted on a free radical-initiated graft copolymer of polyethylene, SEBS, EVA, EPD, or polypropylene, with an unsaturated acid or its anhydride, such as maleic acid, glycidyl methacrylate, ricinoloxazoline maleinate; a graft copolymer of SEBS with glycidyl methacrylate, a graft copolymer of EVA with mercaptoacetic acid and maleic anhydride; a graft copolymer of EPDM with maleic anhydride; a graft copolymer of polypropylene with maleic anhydride; a polyolefin-graft-polyamidepolyethylene or polyamide; and a polyacrylic acid-type compatibilizer.

[0102] According to embodiments, the thread polymer 202 is polar and/or the polymer mixture 100 is apolar.

[0103] **Fig. 3** shows a flowchart that illustrates an example of a method of manufacturing artificial turf fibers 510 as depicted, for example, in figure 5, and of a method of manufacturing an artificial turf 500.

[0104] First, in step 302, a polymer mixture 100, 150, 200 is created. The polymer mixture comprises at least one unaged, long-chain compensatory polymer (made of one or more aged polymers) that is added to the mixture in the form of shredded plastic waste. Optionally, the polymer mixture can further comprise various additives, in particular light stabilizers, a base polymer, an unaged rigid polymer to be used as a thread polymer, and/or a compatibilizer. Various examples of the polymer mixture are depicted and described, for example, in figures 1 and 2.

[0105] According to one example, plastic waste is shredded into aged polymer granules. The aged polymer granules are mixed with compensatory polymer granules; optionally, masterbatch granules comprising additives such as pigments, UV and thermal stabilizers, process aids, and other substances that are known from the art can be added to the mixture. The exact composition of the aged polymers may be unknown.

[0106] The compensatory polymer has a particularly low MFI, being indicative of a particularly high average molecular weight. Preferably, the compensatory polymer is HDPE that has an MFI in the range of 0.6 to 1.2 g/10 min. The compensatory polymer is adapted to compensate for adverse properties of the small average chain length of the aged polymers, such as brittleness and low elasticity. The one or more aged polymers can be provided in the form of shredded plastic waste. The plastic waste can be, for example, ocean plastic waste or artificial turf fibers derived from old used artificial turf fields or any other form of postindustrial or postconsumer plastic waste.

[0107] The polymer mixture may in addition comprise a base polymer, e.g., the polymer contained in a masterbatch that was used for adding the additives to the polymer mixture. Typically, the base polymer is an apolar polymer such as PE, in particular LLDPE. The majority of polymer types contained in heterogeneous plastic waste are also often apolar. Hence, all or at least the majority of the one or more aged polymers will intermix with the base polymer and the compensatory polymer and form a single liquid polymer blend. The polymer mixture can be created by heating the components of a solid polymer mixture 108, 140 above the melting temperature of all polymers contained in the solid polymer mixture. For example, the heating can be performed within an extruder immediately before the extrusion is performed.

[0108] In some embodiments, the artificial turf fiber is created as follows: A polymer mixture 100, 150, 200 is created in step 302 by combining a compensatory polymer and shredded plastic waste in a heatable container, e.g., an extruder. In case the polymer mixture comprises an aged polymer that is not mixable with the other polymers and a compatibilizer, the compatibilizer forms beads within the polymer mixture when the components of the mixture are heated above the melt temperature of the polymers. Likewise, if an unaged, rigid polymer such as PA is added to the polymer mixture to act as a thread polymer, the polymer mixture will also comprise beads consisting of the thread polymer or a thread polymer/aged polymer blend. The polymer beads comprising the thread polymer are, respectively, surrounded by the compatibilizer when the components of the polymer mixture are heated in an extruder for being extruded in step 304 through one or more extrusion holes into a monofilament.

[0109] In some embodiments, the plastic waste is shredded and optionally aggregated and then transferred together with the compensatory polymer and optional additional substances into an extruder. The plastic waste is preferably not processed in order to separate different types of polymers from each other. This may accelerate the process of fiber manufacturing and may reduce costs.

[0110] The melt temperature used during extrusions is dependent on the types of polymers used. However, the melt temperature is typically between 230°C and 280°C.

[0111] Next, in step 304, the polymer mixture is extruded into a monofilament 406, 700, 750. For example, the polymer mixture is fed into a fiber-producing extrusion line. The melt mixture passes the extrusion tool (i.e., a spinneret plate or a wide-slot nozzle), forming the melt flow into a monofilament.

[0112] The extrusion of the polymer mixture can be performed in a so-called one-screw extrusion method or by using a two-screw feed for the extrusion. In this case, the desired amounts of the plastic waste on the one hand and of the compensatory polymer on the other hand can be achieved by using the proper rate or amount of mixing.

[0113] Next, in step 306, the monofilament is quenched or rapidly cooled down, e.g., in a water spin bath, and dried.

[0114] After the monofilament has been cooled down, it is reheated in step 308, and the reheated monofilament is stretched in step 310. The stretching can be performed by passing the monofilament through rotating heated godets with different rotational speeds and/or a heating oven. The stretching of the reheated monofilament deforms the polymer beads, if any, which may already be pre-deformed by the extrusion process, into threadlike regions.

[0115] The reheating and stretching steps are optional. These steps may be advantageous if the polymer blend comprises beads of an immiscible aged polymer or unaged thread polymer that are surrounded by a compatibilizer, because the stretching deforms these beads into threadlike regions that provide extra rigidity and tensile strength to the artificial turf fiber.

[0116] Additional steps may also be performed on the monofilament to form the artificial turf fiber. For instance, the monofilament may be spun or woven into an artificial turf fiber with desirable properties. The artificial turf fiber can be fabricated from one or more of the monofilaments. For example, a plurality of monofilaments can be cabled, twisted, or otherwise bundled together to form a single artificial turf fiber. In other embodiments, each monofilament is used as a respective artificial turf fiber. In some cases, the bundle is rewound with a so-called rewinding yarn, which keeps the yarn bundle together and makes it ready for the later tufting or weaving process. The monofilaments may, for instance, have a diameter of 50 to 600 micrometers. The yarn weight may typically reach 50 to 3,000 dtex.

[0117] The artificial turf fiber is incorporated in step 312 into an artificial turf backing.

[0118] Step 312 could, for example, be - but is not limited to - tufting or weaving the artificial turf fiber into a carrier, e.g., a textile mesh, in step 314.

[0119] Then, in step 316, the artificial turf fibers are bound to the artificial turf backing. For instance, the artificial turf fibers may be glued or held in place by a coating or other material that may be applied in a fluid state onto the lower side of the carrier mesh. Step 318 allows the fluid to solidify into a film that mechanically fixes the fibers in the carrier.

[0120] Steps 316 and 318 are optional steps. For example, if the artificial turf fibers are woven into the carrier, steps 316 and 318 may not need to be performed.

[0121] **Fig. 4** illustrates the extrusion of a multiphase polymer mixture 200 into a monofilament 406. Within the polymer mixture 200, there are a large number of polymer beads. The polymer beads may be made of one or more aged polymers (or an unaged thread polymer, e.g., PA) that are not miscible with the compensatory polymer and the other aged polymers and are separated from the compensatory-aged-polymer blend 100 by a compatibilizer (see figure 2). A screw, piston, or other device is used to force the polymer mixture 200 through a hole 402 in a plate 404. This causes the polymer mixture 200 to be extruded into a monofilament 406. The monofilament 406 is shown as containing a polymer bead 408 that is elongated during the extrusion process to form a threadlike region. In some examples, the polymer mixture 100 will be less viscous than the thread polymer in the beads, and the polymer beads will tend to concentrate in the center of the monofilament 406. This may lead to desirable properties for the final artificial turf fiber.

[0122] The extrusion process can be performed in this same manner for polymer blends 100, 150 that are a one-phase system as depicted, for example, in figures 1A and 1B. In this case, the polymer mixture typically is free of beadlike structures, and the resulting monofilament is free of threadlike regions.

[0123] **Fig. 5** shows an example of a cross section of artificial turf 500 as well as the integration of artificial turf fibers 510 in a carrier 506. The artificial turf fiber may be fabricated in accordance with a method of any one of the embodiments or examples described herein. The artificial turf 500 comprises an artificial turf backing 508 that may, for example, be latex-based or PU-based. Artificial turf fiber 510 has been tufted into the carrier 506, e.g., a textile carrier mesh. The backing 508 is on the lower side of the carrier and embeds U-shaped portions of the integrated fibers, thereby serving to bind or secure the artificial turf fibers 510 to the artificial turf carrier. The backing 508 may be optional. For example, the artificial turf fibers 510 may be alternatively woven into the carrier mesh. Various types of glues, coatings, or adhesives could be used for the backing 508. The artificial turf fibers 510 are shown as extending a distance 504 above the artificial turf carrier 506. The distance is essentially the height of the pile of the artificial turf fibers. The length of the threadlike regions within the artificial turf fibers is half the distance 504 or less.

[0124] The fiber can be mechanically incorporated into the carrier (e.g., by tufting or weaving). For instance, the artificial turf fiber may be inserted with a needle into the carrier and tufted the way a carpet may be. If loops of the artificial turf fiber are formed, they may be cut during the same step. The method further comprises the step of binding the artificial turf fibers to the artificial turf carrier. The incorporation of the artificial turf fiber into the carrier could, for example, be performed alternatively by weaving the artificial turf fiber into a carrier (or fiber mat) as described in United States patent application US 20120125474 A1.

[0125] In a further optional step, the artificial turf fiber is bound or attached to the artificial turf carrier. This may be performed in a variety of ways, such as by gluing or coating the surface of the artificial turf carrier to hold the artificial turf fiber in position. This, for instance, may be done by coating a surface or a portion of the artificial turf carrier with a material such as latex or polyurethane. The coating may comprise applying a liquid backing on a lower side of the carrier and allowing the liquid backing to solidify.

[0126] **Fig. 6A** shows a cross section of a small segment 600 of the monofilament 406 and illustrates the effect of extruding and stretching the monofilament on the beads that may optionally be contained therein. The monofilament is again shown as comprising the polymer mixture 100, with the polymer beads comprising the thread polymer (i.e., an immiscible aged polymer and/or an unaged, preferably rigid and polar polymer such as PA) mixed in. The polymer beads 602 are separated from the other phase 100 of the polymer mixture 200 shown in figure 2 by a compatibilizer. In this figure, an example of a cross section of a monofilament 406 that has been extruded and stretched is shown. To form the threadlike structures, a section of the monofilament 406 is heated and then stretched along the length of the monofilament 406. The polymer beads in figures 1 to 4 have been stretched into threadlike structures 602. The amount of deformation of the polymer beads depends on the extrusion speed and upon how much the monofilament 406 is stretched afterward.

[0127] **Fig. 6B** shows an electron microscope picture of a cross section of a stretched monofilament. This figure more faithfully reproduces the dimensions of the threadlike regions relative to the diameter of the monofilament than does the schematic drawing of figure 6A. The horizontal white streaks within the stretched monofilament 406 are the threadlike regions 602. The threadlike structures 602 can be shown as forming small linear structures of the thread polymer within the homogeneous liquid mixture of the compensatory polymer and the one or more aged polymers.

[0128] The resultant fiber may have multiple advantages - namely, softness combined with durability and long-term elasticity. In cases of different stiffness and bending properties of the polymers, the fiber can show a better resilience (this means that once a fiber is stepped on, it will spring back). In cases of a stiff thread polymer, the small linear fiber structures built into the polymer matrix provide a polymer reinforcement for the fiber.

[0129] Delimitation due to the composite formed by the thread polymer and the other phase of the polymer mixture is prevented, as the thread polymer is finely dispersed and embedded by the compatibilizer. Moreover, complicated co-extrusion machines with several extrusion heads to feed one complex spinneret tool are not needed.

[0130] The thread polymer can be a polar substance, such as polyamide, whereas the other phase of the polymer mixture 200 can be an apolar polymer, such as polyethylene. Alternatives for the thread polymer are PET and PBT.

[0131] **Fig. 7** shows three cross sections of artificial turf fibers having a core-cladding structure.

[0132] **Fig. 7A** shows a cross section of an artificial turf fiber 700 created by concentric co-extrusion of at least a first polymer mass 702 and a second polymer mass 704. The fiber 700 is created by extruding the first and the second polymer mass together through a common extrusion path such that the first polymer mass is concentrically surrounded by the second polymer mass 704 and such that the two polymer masses are in contact (at a contact area 706 depicted in figures 7B and 7C - while being co-extruded through the common extrusion path.

[0133] According to one embodiment (not shown), the first polymer mass 702, which may also be referred to as a "core polymer" or "core polymer mass," is a single-phase molten polymer blend as depicted - for example, in figures 1A and 1B. The blend can be free of any beads and can be free of a compatibilizer.

[0134] According to other embodiments (depicted in figures 7A, 7B, and 7C), the first polymer mass 702 is a multiphase polymer mixture 200 as depicted, for example, in figure 2.

[0135] The second polymer mass 704 - which may also be referred to as "cladding polymer" or "cladding polymer mass" - is an unaged cladding polymer. The cladding polymer is miscible with the core polymer or at least with the phase of the core polymer mass that surrounds and embeds the compatibilizer-coated thread polymer.

[0136] This may be advantageous, as the miscibility of the core polymer and the cladding polymer ensures that the two types of polymers or polymer blends slightly intermix at the contact zone 706, thereby preventing a delamination of the cladding and the core at the contact zone 706. Moreover, according to preferred embodiments, pigments, flame retardants, and/or light stabilizers are selectively added to the cladding polymer mass 704 or are added such that they have a higher concentration in the cladding polymer than in the core polymer 702. This may allow lowering the production costs without reducing the quality of the fiber.

[0137] As a further beneficial aspect, using the concentric core-cladding structure as depicted in figures 7A, 7B, and 7C may ensure that even in cases where the mechanical properties of the polymer mixture 100, 150, 200 should be worsened by a large portion of an aged polymer, the fibers 700, 750 do not have these worsened mechanical properties because they have (a) a compensatory polymer that is intermixed with the aged polymers and (b) a shell/cladding that is made completely of an unaged polymer, e.g., PE or PP.

[0138] **Figs. 7B and 7C** show another embodiment of a fiber 750 having a core-cladding structure whereby the core is made of a mixture described herein for embodiments of the invention and whereby the cladding is made of an unaged polymer that is identical to the base polymer of the core 702. The fiber 750 comprises two protrusions 704 that consist of the cladding polymer and increase the surface-to-mass ratio of the fiber.

[0139] According to one example, the monofilaments 700, 750 formed by co-extrusion of the core polymer mass 702 with the cladding polymer mass 704 may already feature a robust bond between core and cladding. A high elasticity offered by a rigid thread polymer may be reached by elongating and stretching the beads into threadlike regions. This extension may be achieved by reheating the monofilament and stretching it over a controlled length ratio. As a result, an artificial turf fiber is formed; this fiber may feature a high resilience due to a highly elastic core, optimized surface properties due to an appropriate choice of the cladding polymer, and inherent protection from splicing or delamination due to a highly stable contact layer where the core polymer is mixed with the cladding polymer.

[0140] Embodiments of the invention include forming the artificial turf fiber 750 with particular geometry features of the noncircular profile.

[0141] **Fig. 8** shows an extrusion head for co-extruding two polymer masses. The head comprises two separate openings for two different polymer masses that allow generating an artificial turf fiber monofilament 700, 750 having a core-shell structure in a co-extrusion process.

[0142] The first polymer mass 702, also referred to as a core polymer mass, is fed through a first opening into a duct that is located at the center of the extrusion head. The second polymer mass 704, also referred to as a cladding polymer mass, is fed through one or more further openings into a second duct that concentrically surrounds the first duct.

[0143] At first, the molten cladding polymer 704 and the molten core polymer 702 are transported along their respective ducts toward the opening 702 of the extrusion head. The transportation of the polymer masses in their respective ducts is performed such that the two polymer masses are transported in a basically laminar flow. While the two polymer masses are transported in their respective ducts, an intermixing of the core and the cladding polymer mass is prohibited by the walls of the inner duct. The first duct, used for transporting the core polymer mass, is shorter than the second duct, used for transporting the cladding polymer mass. As a result, the two polymer masses come into contact with each other when the core polymer mass leaves the end of the inner duct. The portion where the core and the cladding polymer mass come into contact with each other and can intermix at the contact area 706 is referred herein as a "joining path" 760.

[0144] The co-extrusion comprises extruding the core polymer mass and the cladding polymer mass together through a common extrusion path ("joining path") such that the core polymer mass is concentrically surrounded by the cladding polymer mass, and such that the two polymer masses are in contact while being co-extruded through the common extrusion path. The core polymer mass is the polymer mixture created in a method as described herein for embodiments of the invention. The cladding polymer mass is an unaged cladding polymer, e.g., PE, in particular LLDPE. The cladding polymer is miscible with the core polymer or at least with the main component of the core polymer.

[0145] According to embodiments, the extrusion opening is located downstream of the joining path 760 wherein the core and cladding polymer masses 702, 704 are allowed to contact each other while moving in parallel, with a laminar flow, toward the opening 402. This may allow the core and cladding polymer to intermix at the contact zone 706, thereby preventing a delamination of the cladding from the core.

[0146] The length, diameter, and feeding rate of both polymers are chosen such that the core polymer mass and the cladding polymer mass contact each other in such a way that a contact layer 706 is formed between the core polymer mass and the cladding polymer mass, the contact layer comprising a mixture of the core polymer mass and the cladding polymer mass. This may be achieved by controlling the flow characteristics (streaming pattern, velocity distribution, viscosities, shear moduli, temperature, MFIs, etc.) during the joining such that a stable, small-scale turbulence is created, which causes the two polymer masses to intermix in a thin region 706, interfacing the core polymer mixture and the cladding polymer component. This may strengthen the cohesion between the core and cladding of the finished artificial turf fiber.

[0147] According to embodiments, the core polymer mass and the cladding polymer mass are pressed concentrically along the joining path 760 such that the core polymer and the cladding polymer are allowed to mix along the joining path to form the contact layer 706. The contact layer is formed within an axial length of the joining path of three to seven times the diameter of the inner duct used for transporting the core polymer mass at the upstream end of the joining path 760. According to embodiments, the diameter of the core polymer mixture at the upstream end of the joining path is between 0.5 and 1.5 mm, preferably 1.25 mm. This may allow for adjusting the length of the joining path to the specific properties, such as viscosity, MFI, or shear modulus, of the polymer components to be brought into contact, as well as to the specific process parameters, such as temperature or pressure, to provide beneficial rheological properties for establishing a firm bond between the core and the cladding of the fiber. The flow in the joining path should be maintained at a stable, small-scale turbulence. If the length of the joining path is too long, turbulence may get suppressed by feedback of increased wall-polymer interaction. On the other hand, a too-short joining path may destroy the stability of the turbulence such that the contact layer becomes variable, e.g., in thickness and position. A fiber produced with a too-short joining region may show no beneficial surface properties, which are supposed to arise from a clear distinction between the core and cladding.

[0148] According to embodiments, the core of the fiber has a diameter of 50 to 600 micrometers, and the cladding is formed with a minimum thickness of 25 to 300 micrometers in all directions, extending radially from the core. Each of the protrusions, if any, is formed with a radial extension in a range of two to 10 times the radius of the core. As explained further above, the mentioned ranges for the core diameter and the minimum cladding thickness may be beneficial for providing the desired degree of stiffness and a sufficient amount of cladding material surrounding the core to form the mechanically robust contact layer. Said ratio of the radial extension of the protrusions with respect to the core radius may be chosen so as to improve the biomimetic properties of the artificial turf and the surface-to-mass ratio of the artificial turf fibers.

[0149] The opening 402 of the extrusion head can have a circular profile, resulting in a monofilament profile as depicted in figure 7A.

[0150] Alternatively, the opening 402 can have a non-circular profile. According to embodiments, the resulting monofilament profile comprises one or more protrusions that extend from the core in opposite directions, as depicted in figures 7B and 7C.

List of reference numerals

[0151]

100	molten polymer mixture
102	base polymer
104	compensatory polymer
106	aged polymer(s)
108	solid polymer mixture
140	solid polymer mixture
150	molten polymer mixture
200	molten polymer mixture
202	thread polymer
204	compatibilizer
302-318	steps
402	extrusion opening
404	extruder plate
406	extruded monofilament
408	elongated beadlike structure
500	artificial turf
502	cutting tufted fibers
504	fiber portions protruding from the carrier
506	carrier
508	backing
510	artificial turf fibers
600	section of a monofilament
602	threadlike regions
700	monofilament
702	first polymer mass (core polymer)
704	second polymer mass (cladding polymer)
706	contact area core/cladding polymer
750	monofilament
760	joining path
770	extrusion head of co-extruder

Claims

1. A method of manufacturing an artificial turf fiber (510), the method comprising:

   - creating (502) a polymer mixture (100, 150, 200) comprising molten plastic waste and a molten compensatory polymer (104), the plastic waste comprising one or more aged polymers (106), the compensatory polymer being an unaged polymer, the melt flow index of the compensatory polymer being at least four times lower than the melt flow index of the one or more aged polymers;
   - extruding (304) the polymer mixture into a monofilament (406); and
   - fabricating the artificial turf fiber from one or more of the monofilaments.

2. The method of claim 1, wherein the polymer mixture further comprises a base polymer (102), the base polymer being an unaged polymer, the base polymer being in particular polyethylene.

3. The method of claim 2, wherein the base polymer has a melt flow index in the range of 2.0 to 5.0 g/10 min.

4. The method of any one of the previous claims 2 or 3, wherein the polymer mixture comprises the base polymer in an amount of at least 5% by weight of the polymer mixture, in particular in an amount of 5 to 10% by weight of the polymer mixture.

5. The method of any one of the previous claims, wherein the compensatory polymer is HDPE or LDPE.

6. The method of any one of the previous claims, wherein the compensatory polymer has a melt flow index in the range of 0.6 to 1.2 g/10 min.

7. The method of any one of the previous claims, wherein the polymer mixture comprises the compensatory polymer in an amount of 5 to 15% by weight of the polymer mixture.

8. The method of any one of the preceding claims, wherein at least 1%, e.g., at least 10%; e.g., at least 40%; or at least 60% by weight of the polymer mixture consists of the plastic waste.

9. The method of any one of the previous claims, wherein the one or more aged polymers respectively have a melt flow index in the range of 5.0 to 7.0 g/10 min.

10. The method of any one of the preceding claims, wherein the plastic waste is a shredded, cut, crushed, minced, or ground plastic waste of heterogeneous origin, in particular shredded postconsumer plastic waste.

11. The method of any one of the previous claims, wherein the plastic waste consists of or comprises ocean plastics.

12. The method of any one of the previous claims, wherein the plastic waste comprises used artificial turf fibers, in particular a mixture of different types of used artificial turf fibers.

13. The method of any one of the previous claims, wherein the polymer mixture comprises light stabilizers in an amount of at least 0.6% by weight of the polymer mixture, preferably in the range of 0.7% to 1.2% by weight of the polymer mixture.

14. The method of claim 13, the light stabilizer being hindered amine light stabilizers (HALS).

15. The method of any one of the previous claims, the polymer mixture being a blend of molten polymers.

16. A method of manufacturing artificial turf (500), the method comprising:

- incorporating (312) a plurality of artificial turf fibers (510) manufactured according to any one of the previous claims into a carrier (506).

17. An artificial turf fiber (510) manufactured according to the method of any one of the preceding claims.

18. An artificial turf fiber (510) comprising at least one monofilament (406), wherein each of the at least one monofilament comprises:

- one or more aged polymers (106) and
- a compensatory polymer (104), the compensatory polymer being an unaged polymer, the melt flow index of the compensatory polymer being at least four times lower than the melt flow index of the one or more aged polymers, wherein the monofilament is an extruded product of a polymer mixture comprising the base polymer, the one or more aged polymers, and the compensatory polymer.

19. The artificial turf fiber (510) of claim 18, wherein the at least one monofilament has a core-cladding structure, wherein the core is made of a core polymer mixture and the cladding is made of a cladding polymer, the core polymer mixture comprising the one or more aged polymers (106) and the compensatory polymer.

20. An artificial turf (500) comprising a carrier (506) and an artificial turf fiber (510) according to claim 18 or 19, the fiber being incorporated into the carrier.

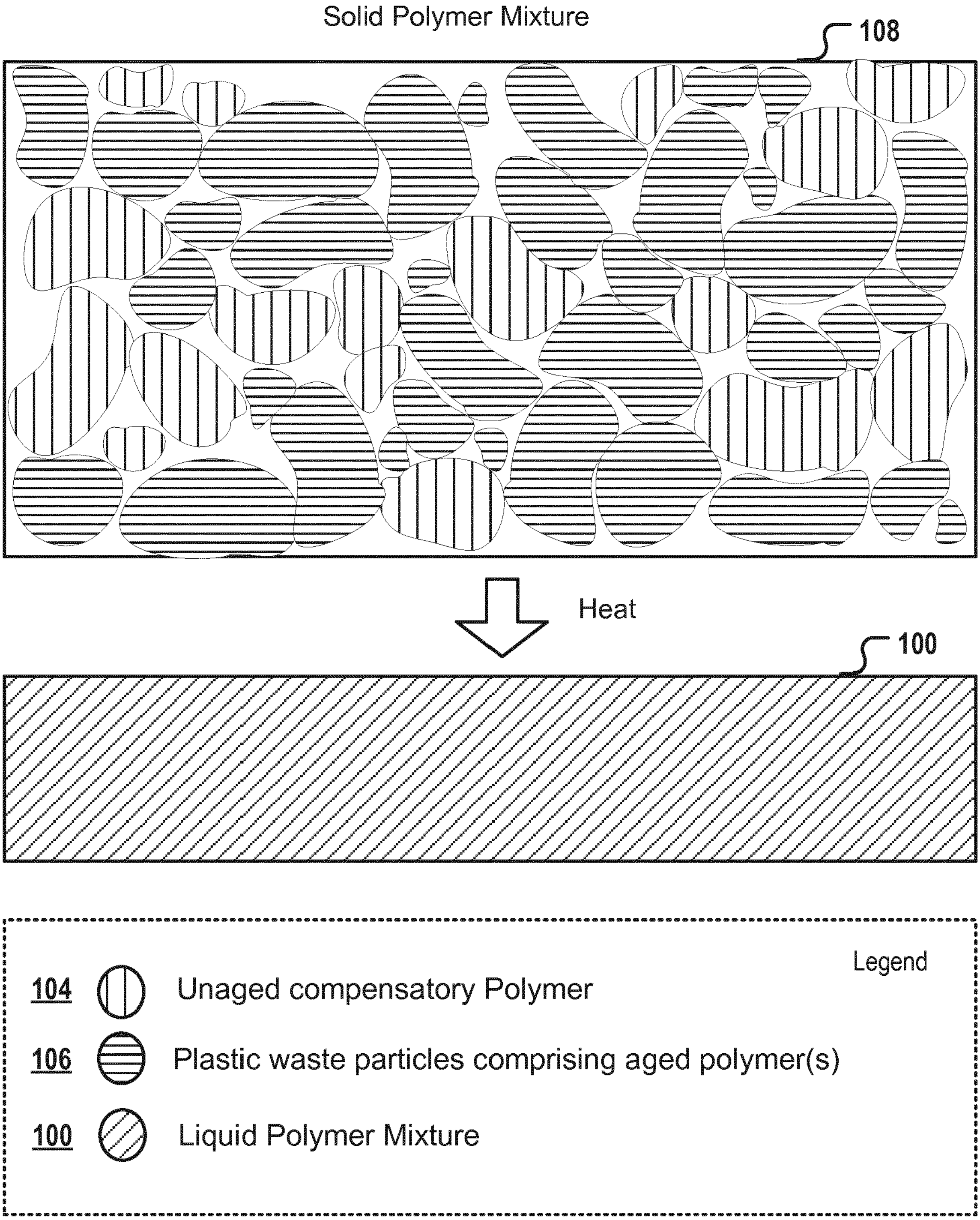

Solid Polymer Mixture
108
Heat
100
Legend
104 Unaged compensatory Polymer
106 Plastic waste particles comprising aged polymer(s)
100 Liquid Polymer Mixture

Fig. 1A

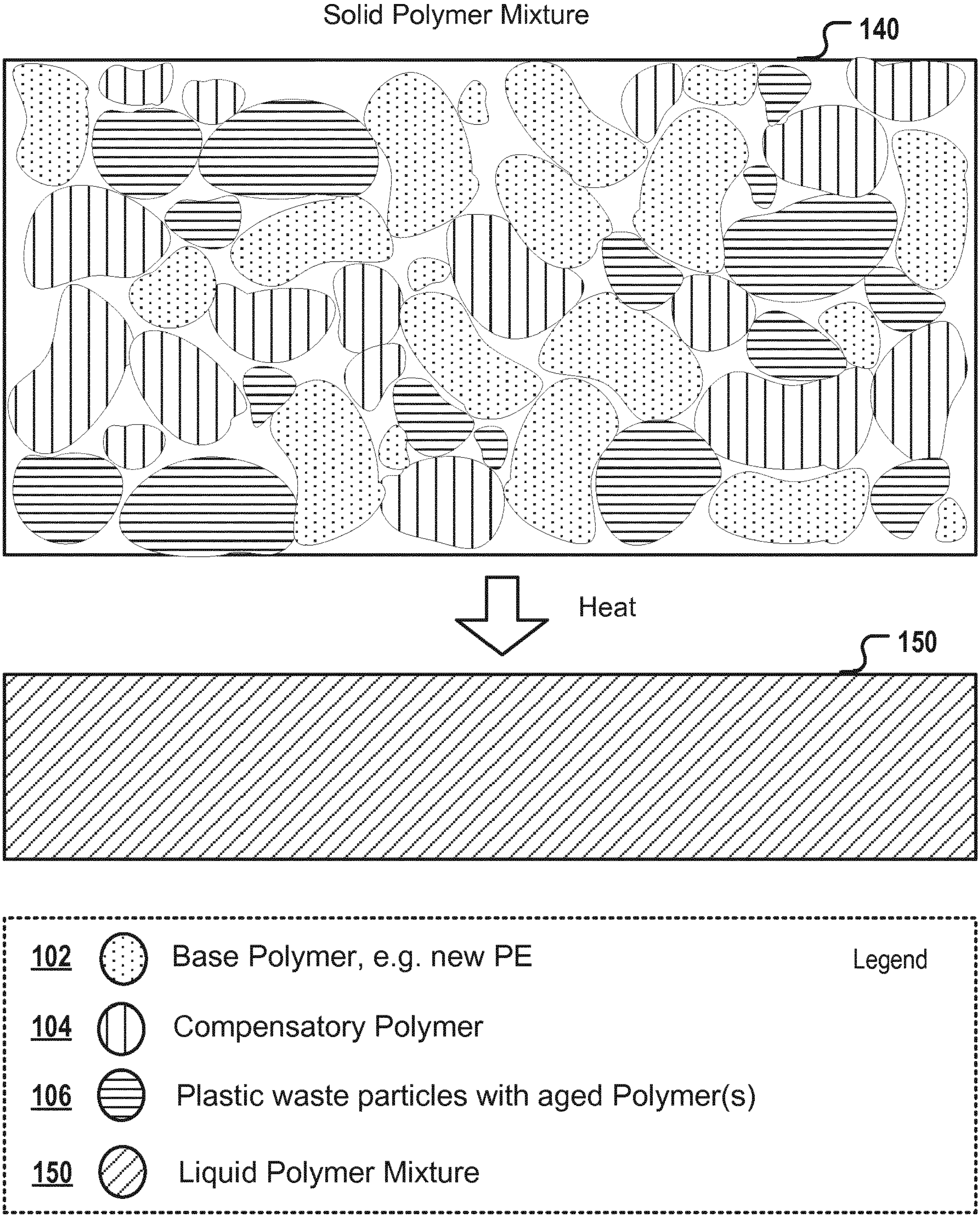
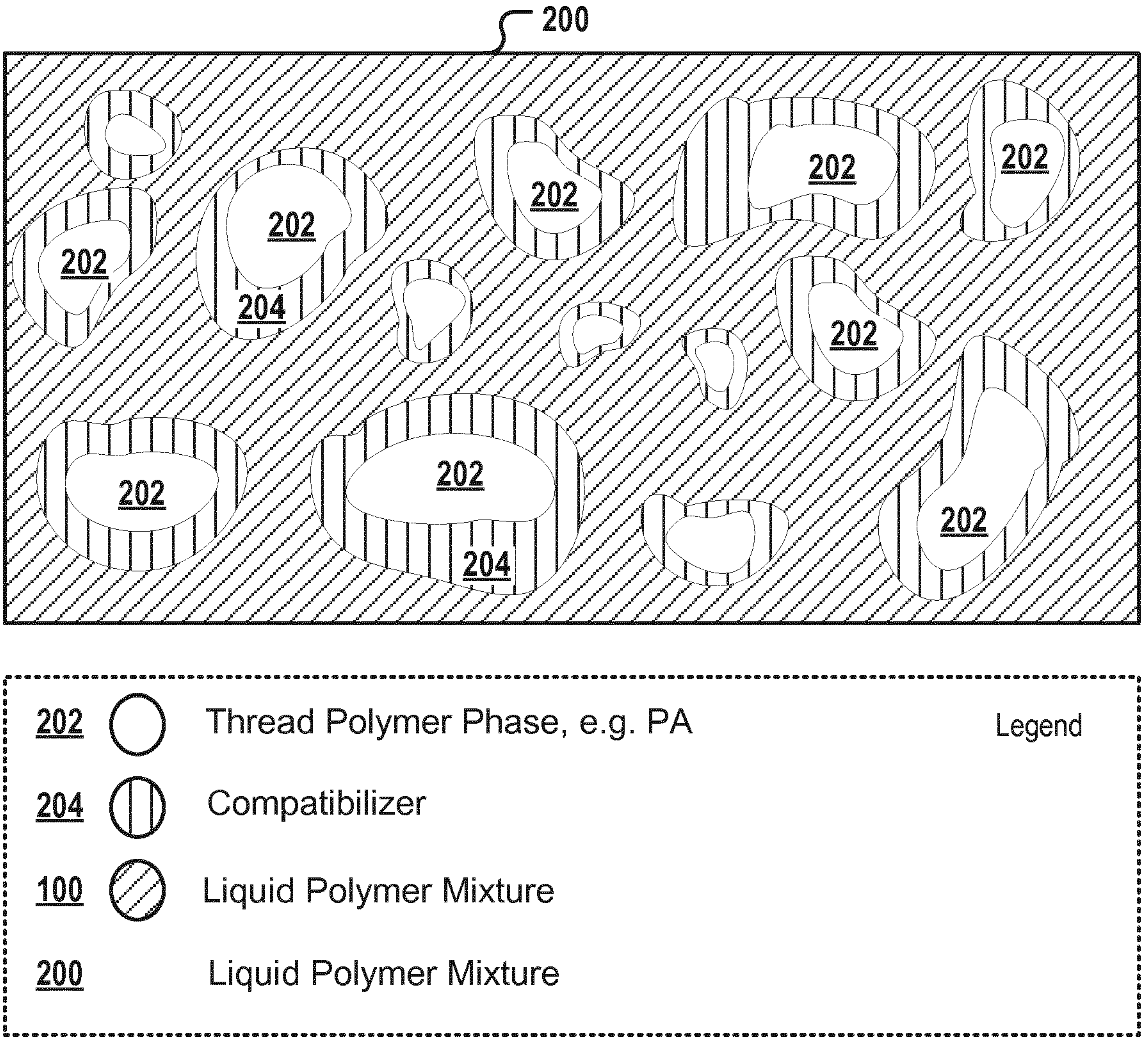

Solid Polymer Mixture
140
Heat
150
102 Base Polymer, e.g. new PE
Legend
104 Compensatory Polymer
106 Plastic waste particles with aged Polymer(s)
150 Liquid Polymer Mixture

Fig. 1B


200
202
202
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202 Thread Polymer Phase, e.g. PA
Legend
204 Compatibilizer
100 Liquid Polymer Mixture
200 Liquid Polymer Mixture

Fig. 2

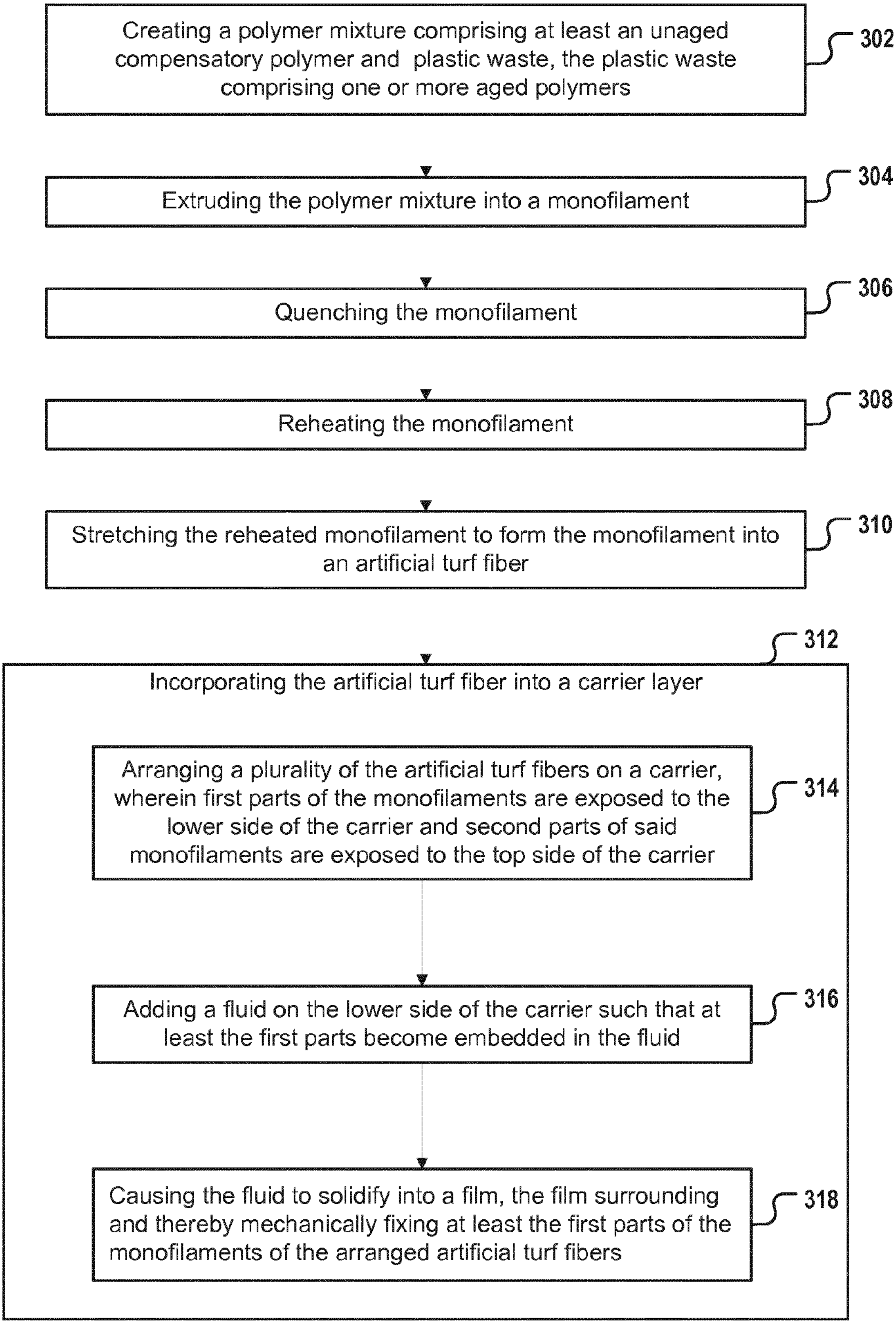
Creating a polymer mixture comprising at least an unaged compensatory polymer and plastic waste, the plastic waste comprising one or more aged polymers
302
Extruding the polymer mixture into a monofilament
304
Quenching the monofilament
306
Reheating the monofilament
308
Stretching the reheated monofilament to form the monofilament into an artificial turf fiber
310
312
Incorporating the artificial turf fiber into a carrier layer
Arranging a plurality of the artificial turf fibers on a carrier, wherein first parts of the monofilaments are exposed to the lower side of the carrier and second parts of said monofilaments are exposed to the top side of the carrier
314
Adding a fluid on the lower side of the carrier such that at least the first parts become embedded in the fluid
316
Causing the fluid to solidify into a film, the film surrounding and thereby mechanically fixing at least the first parts of the monofilaments of the arranged artificial turf fibers
318

Fig. 3

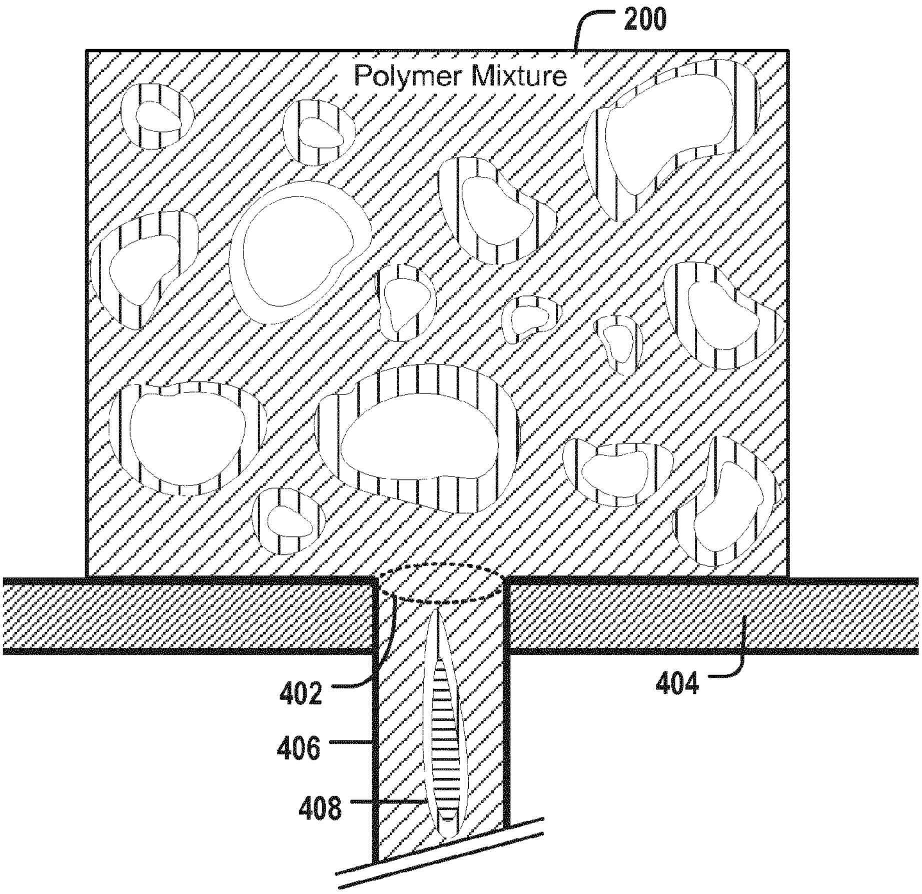

Fig. 4

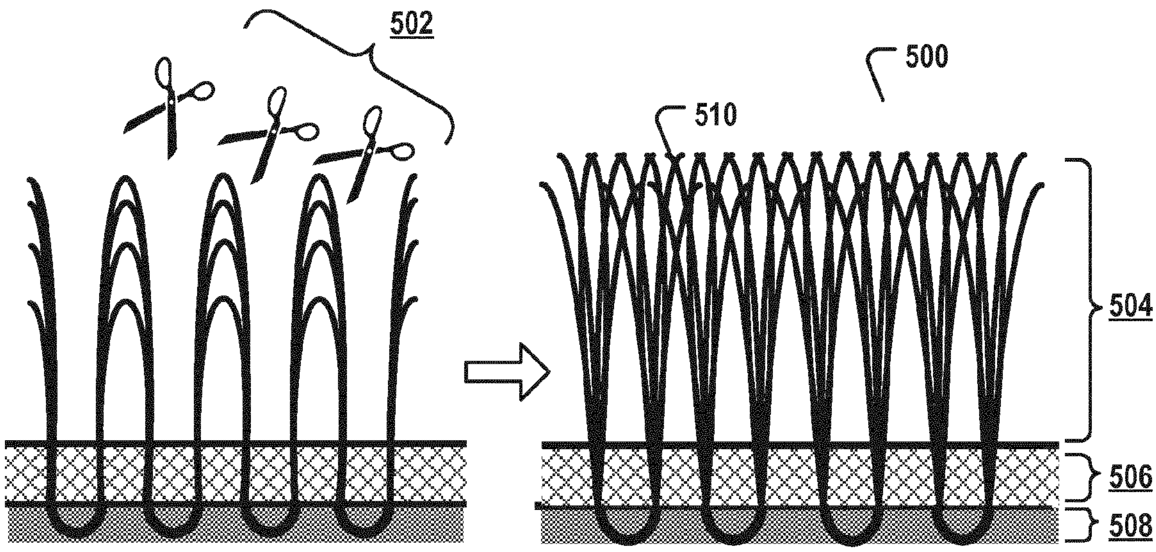

Fig. 5A

Fig. 5B

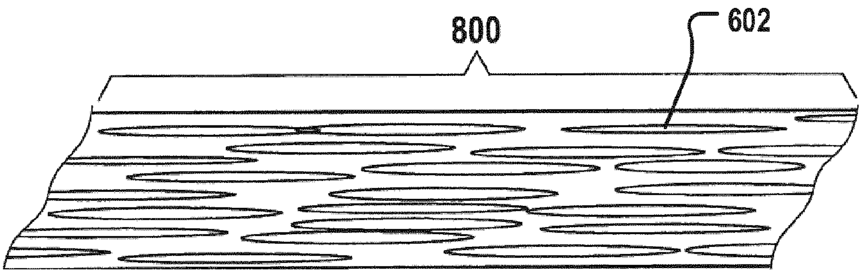

Fig. 6A

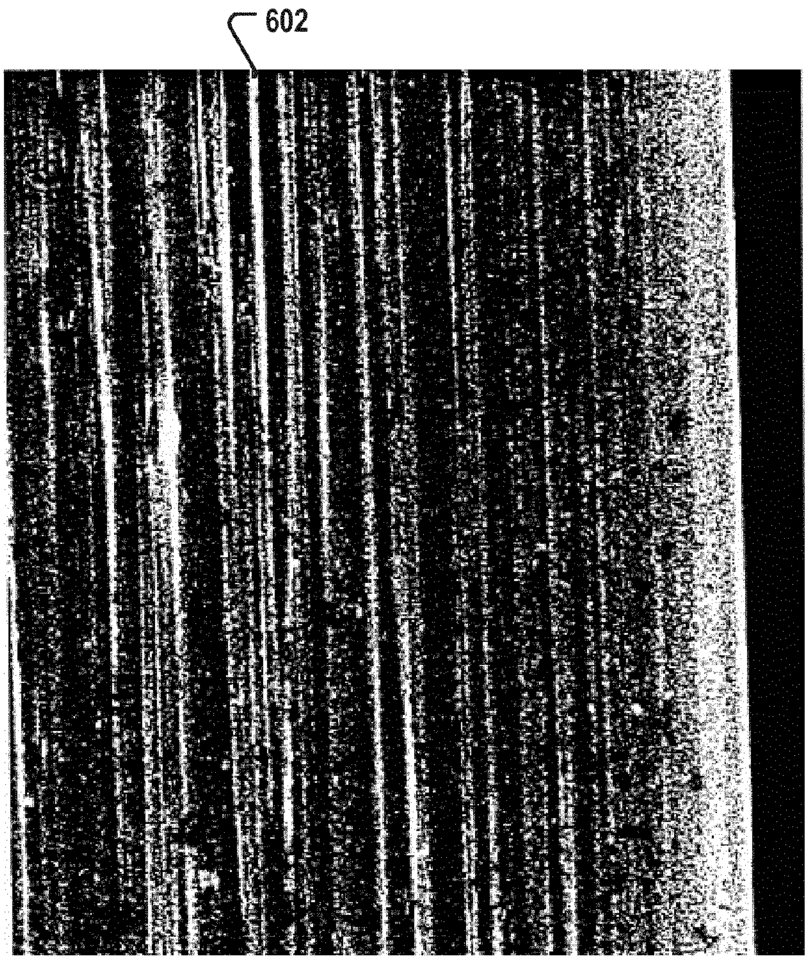

Fig. 6B

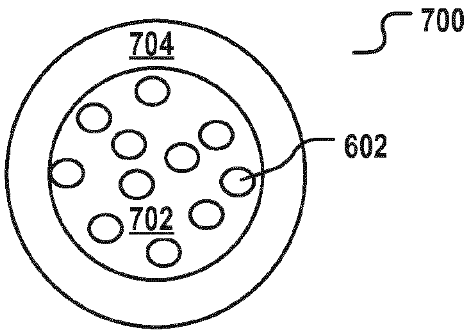

Fig. 7A

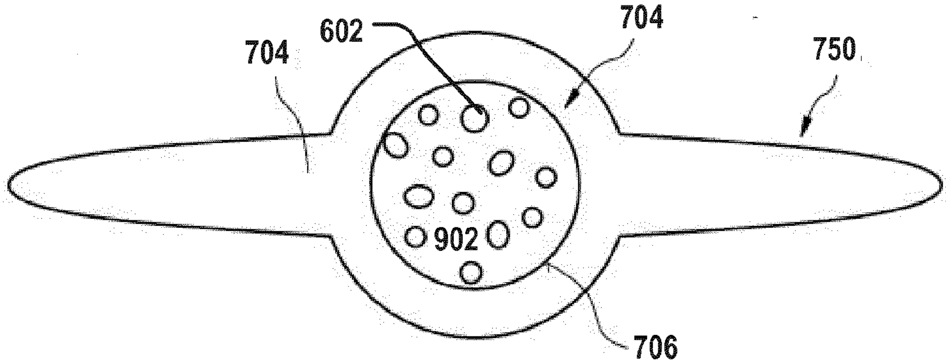

Fig. 7B

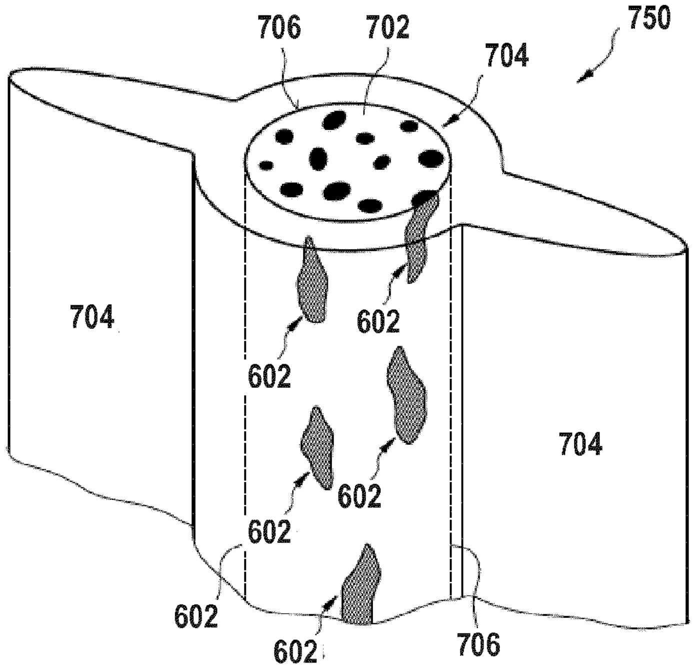

Fig. 7C

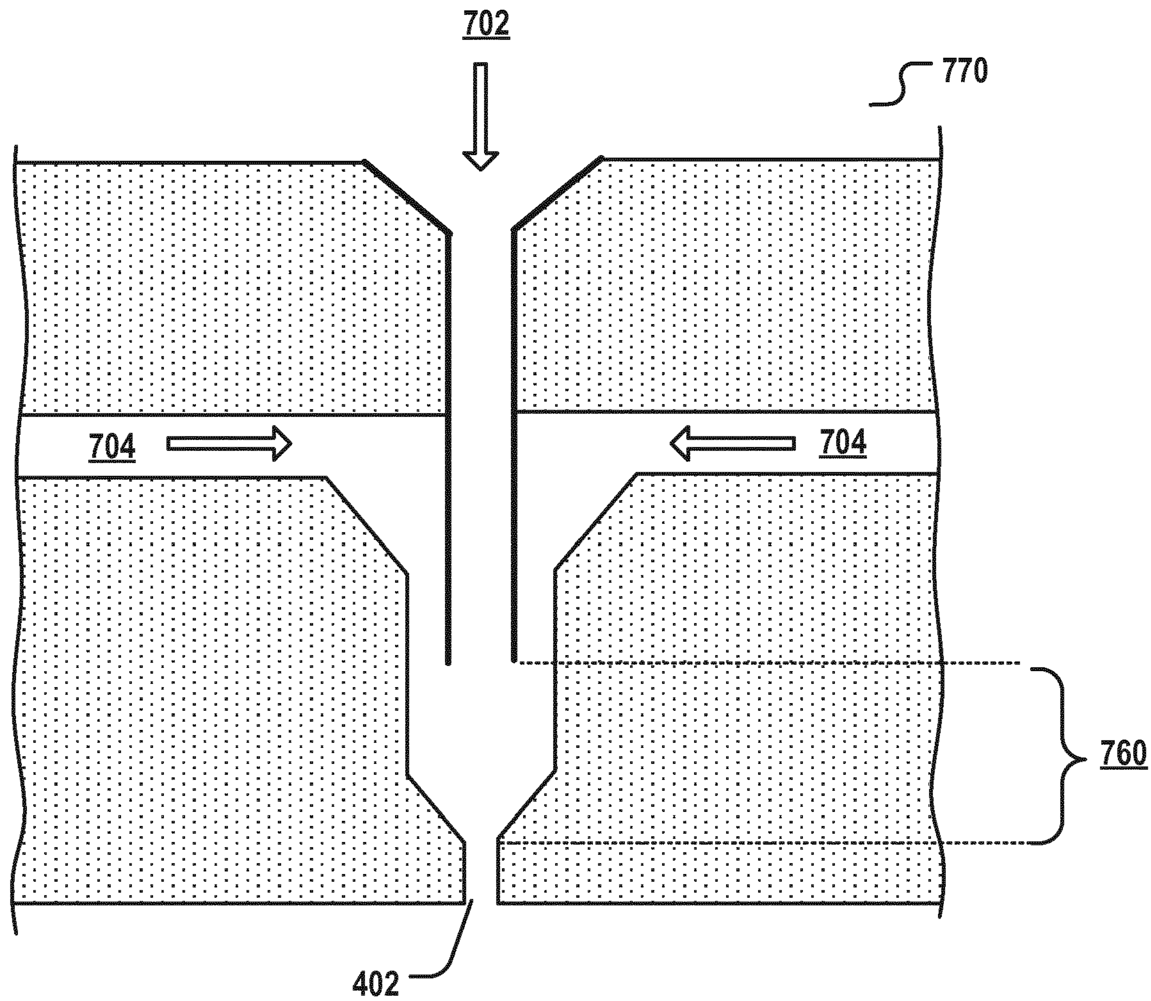

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 18 18 6327

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	JP 2007 016367 A (HAGIHARA IND) 25 January 2007 (2007-01-25) * abstract * * example 1 * -----	1-20	INV. E01C13/08 D01F6/46 ADD. D01D5/253 D01D5/34 D01F8/06
A	WO 2018/077850 A1 (POLYTEX SPORTBELAEGE PRODUKTIONS GMBH [DE]) 3 May 2018 (2018-05-03) * claims 1-11 * * figures 1,2,4-7 * -----	1-20	
A	EP 3 272 939 A1 (POLYTEX SPORTBELÄGE PRODUKTIONS-GMBH [DE]) 24 January 2018 (2018-01-24) * pages 0021,002 * * claims 1,2,5,11,12 * * figures 1-5,8 * -----	1-20	
			TECHNICAL FIELDS SEARCHED (IPC)
			E01C D01D D01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	29 November 2018	Verschuren, Jo

CATEGORY OF CITED DOCUMENTS

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L : document cited for other reasons
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2

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 18 6327

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29-11-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2007016367 A	25-01-2007	NONE	
WO 2018077850 A1	03-05-2018	EP 3315640 A1	02-05-2018
		WO 2018077850 A1	03-05-2018
EP 3272939 A1	24-01-2018	EP 3272939 A1	24-01-2018
		WO 2018015396 A1	25-01-2018

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Patent documents cited in the description

- EP 2161374 B1 **[0004]**
- US 20120125474 A1 **[0124]**