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(71) Applicant: **Helmholtz-Zentrum hereon GmbH**
21502 Geesthacht (DE)

(72) Inventors:
• **FARHAN, Muhammad**
12279 Berlin (DE)
• **IZRAYLIT, Victor**
10179 Berlin (DE)
• **HERRMANN, Sarai**
12055 Berlin (DE)

(74) Representative: **Gruner, Leopold Joachim**
White ip | Patent & Legal GmbH
Königstraße 7
01097 Dresden (DE)

(54) **TWO-WAY SHAPE MEMORY POLYMER APPLICATIONS**

(57) The present invention relates to the field of textiles, especially shape memory textiles and discloses a two-way shape memory polymeric textile and the covered two-way shape memory polymeric fiber comprised therein, a method and applications thereof.

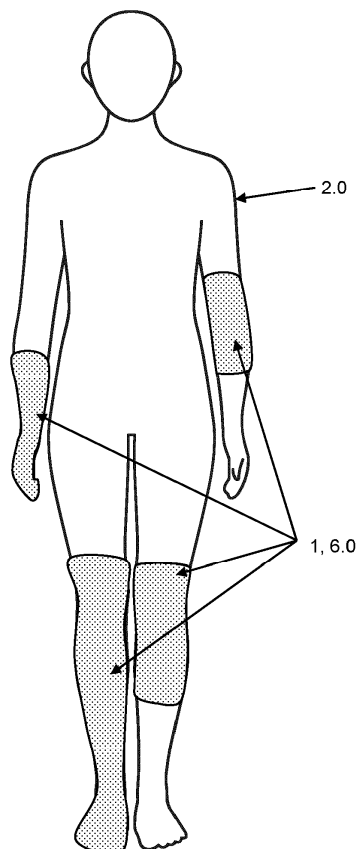


Fig. 5

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Description

TECHNICAL AREA

[0001] The present invention is in the field of functional and programmable textiles, especially shape memory textiles. It discloses a two-way shape memory polymeric textile (2W-SMT) and as well as a covered two-way shape memory polymeric fiber (2W-cSMPF), comprised therein, a method for programming the textile (2W-SMT) comprising the 2W-cSMPF(s) and its applications.

STATE OF THE ART

[0002] Shape memory polymers (SMPs) are an emerging class of smart materials that can change their size and shape in response to external stimuli such as heat, electric current, and alternating magnetic field, water or light. Typical SMPs have the ability to remember their original shape after deformation, such as stretching. They maintain the deformed state, also referred to as programmed state, in the absence of the stimulus and return to their original shape, also called the initial state, after the application of the external stimulus. SMPs are increasingly being investigated for various applications. From a structural point of view, SMPs can be classified into three-dimensional systems, such as shape memory blocks or shape memory foams, two-dimensional systems, such as shape memory films, and one-dimensional systems, such as shape memory fibers, of which shape memory polymeric fibers have attracted the most attention. In woven, non-woven, or knitted form, shape memory fibers can be converted into two- and/or three-dimensional systems, also referred to as textiles or fabrics.

[0003] A specific subclass of SMPs are two-way shape memory polymers (2W-SMP), which, in addition to the one-way shape memory (1W-SM) effect, have at least two different sets of states that can be switched according to external stimulation, referred to as two-way shape memory (2W-SM) effect. These are comprised of at least two phases or domains, consisting of different switching segments or components with different transition or switching conditions, such as temperature change, electromagnetic fields, electric currents, or alternating magnetic field, and are therefore able to store two temporary shapes in their "shape memory" (SM) in addition to their permanent shape.

[0004] Examples of temperature-activated two-way shape memory polymers include US 10,040,880 B2, which discloses a bidirectional shape memory polymer having first and second phase-separated domains with corresponding transition temperatures. Another related example was reported by BEHL, Marc et al. Reversible Bidirectional Shape-Memory Polymers. *Adv. Mater.* 2013, Vol.25, No.32, pages 4466-4469, ISSN 0935-9648, doi:10.1002/adma.201300880, which dis-

closes reversible bidirectional shape memory polymers having two different sets of crystallizable domains, one of which determines the shape-shifting geometry while the other provides the thermally controlled actuation capability.

[0005] Examples of magnetic actuation include a paper by WANG, Li et al. Reprogrammable, magnetically controlled polymeric nanocomposite actuators. *Mater. Horiz.* 2018, Vol.5, No.5, pages 861-867, ISSN 2051-6347, doi:10.1039/C8MH00266E, which discloses a hybrid polymeric nanocomposite actuator comprising magnetic nanoparticles, which enable actuation through inductive heating. RAZZAQ, Muhammad Yasar et al. Matching Magnetic Heating and Thermal Actuation for Sequential Coupling in Hybrid Composites by Design. *Macromol. Rapid Commun.* 2020, Vol.41, No.1, article no. 1900440, ISSN 1022-1336, doi:10.1002/marc.201900440, reported a nanocomposite material comprising an inner actuator that can be remotely heated by exposure to an alternating magnetic field (AMF) and outer layer(s) of a porous composite system.

[0006] Various materials are known in the literature to provide a 2W SMP. As an example of thermal polymer materials, FARHAN, Muhammad et al. Origami hand for soft robotics driven by thermally controlled polymeric fiber actuators. *MRS Commun.* 2021, Vol.11, No.4, pages 476-482, ISSN 2159-6867, doi:10.1557/s43579-021-00058-4, disclose a cross-linked poly(ethylene-co-vinyl acetate) (cPEVA)-based 2W-SMP utilized in robotic actuators by thermal control.

[0007] For example, patent specification EP 2 935 413 B1 describes a bidirectional shape memory polymer, as well as a method for its production, wherein the bidirectional shape memory polymer has two phase-separated domains and is characterized by covalent or physical bonds that cross-link the polymer chains, thus connecting the first and second domains. The polymer can be converted from one form to the other by changing the temperature. Another approach is described in patent document US 11,926,932 B2, wherein a multicomponent shape memory thread material that consists of multicomponent shape memory filaments, fibers, tubes or tapes containing at least two shape memory polymer components that have a shape recovery temperature between about 0 °C and 130 °C. When heated, the multicomponent system assumes a substantially spiral configuration. The patent specification WO 2008/101760 A1 discloses a method for single-step programming of three-shape plastics, which relates to thermally activated two-way shape memory polymers, in particular to a method for producing a programmed shape memory polymer that takes on a first temporary shape and has at least two further stored, thermally retrievable shapes. All of these shape-memory polymers are limited in their application by their inherent tendency to be overstretched during program-

ming or during use, resulting in irreversible damage and a low shape-fixity rate.

[0008] Furthermore, a number of attempts have been made to incorporate functional materials, such as SMP(s) or electrically stimulated materials, into fabrics and textiles to achieve customized fits or modulated abilities.

[0009] WO 2012/045427 A1 discloses medical aids, in particular support bandages and orthoses, which comprise at least one element that generates or exerts a supporting force, compression, or pressure effect and which comprises or consists of shape memory material. The programmed shape memory transition of the medical device is triggered by body heat, causing the stretched shape of the medical device, which facilitates application to the body, to transition to a contracted shape that provides the support and/or compression effect of the medical device. The shape memory material according to this disclosure is a composite, a mixture, an alloy, or a composite material with different shape memory effects.

[0010] Patent specification EP 3 638 175 B1 describes a contractible band for use in a wearable garment, comprising a shape memory material part, in particular an electrically contractible shape memory material, and a spring arranged to reverse the contraction of the shape memory material. The disadvantages of this are that the contractible band has a series of exposed elements and that a spring is needed to reverse the contraction of the shape memory material.

[0011] Patent document US 10,383,375 B2 relates to shape-changing fibers that can respond to various stimuli from the environment, and to garments made from such fibers. The stimuli may include humidity, temperature, electric fields, magnetic fields, etc. This is achieved by means of a complex fiber structure that has several cross-sectional and radially symmetrical shapes.

[0012] US 11,773,516 B2 describes an intelligent textile that changes its porosity, shape, texture, bulk, stiffness or color by temperature change or moisture absorption using torsion and tension actuators made of polymer fibers, which are designed as twisted or coiled polymer fiber actuators that are spiral in shape. These intricately constructed fibers are limited by their architectural concept and complex in their design and application.

[0013] Patent specification WO 2015/038599 A1 discloses a compression garment with a homogenous active textile element formed of a shape memory alloy (SMA) material for at least partially encircling a wearer's body part of interest, which is intended to exert a controllable compression on the body part of interest. Only a simple shape memory polymer has been disclosed, so to remove the pressure, the entire textile must be reprogrammed and then readapted.

[0014] Lastly, WO 2022/207351 A1 discloses a functional tissue or device comprising flexible tissues or

fiber-based materials that reversibly change their shape upon stimulation with temperature and/or electricity (electric field and/or charge) and/or upon application of tension, wherein the tissue preferably exhibits different states. This application mainly refers to the haptic effect, such as the glass-like (hard feel) and rubber-like (soft feel) state when the temperature changes.

[0015] To date, no methods and products are known that can specifically produce a reproducible textile with a 2W shape memory effect with high deformation fixation efficiency (Q_{ef}) and shape recovery ratios.

OBJECTION OF THE INVENTION

[0016] The object of the present invention is to address and overcome a major shortcoming in the field of shape memory textiles as observed in the prior art. Conventional shape memory textiles can be conformed to a specific contour and provide defined properties such as a defined compression pressure, but are limited in their application by a low deformation fixation efficiency and shape in the programmed states due to overstretching, and their inability to be easily removed while in the programmed, shrunk state.

[0017] It is therefore an object of the present invention to develop a two-way shape memory textile (2W-SMT) comprising two-way shape memory polymeric fibers (2W-SMPF), in particular two-way covered shape memory polymeric fibers (2W-cSMPF), which retain their shape memory capabilities even in circumstances where they can be subjected to strains exceeding their conventional application limits.

SOLUTION

[0018] The problem is solved by a two-way shape memory textile (2W-SMT) comprising two-way shape memory polymeric fibers (2W-SMPF) of claim 1. The invention further discloses a method of making the same as well as a shape memory fiber comprised by the same.

[0019] Further advantageous embodiments and further developments are shown in the subclaims and in the description with reference to the figures.

GENERAL ADVANTAGES

[0020] The invention provides a two-way shape memory textile (2W-SMT) which synergistically overcomes a number of disadvantages of the state of the art: By incorporating a two-way covered shape memory polymeric fiber (2W-cSMPF) into the base fiber and/or base fabric, the textile may be adapted to a specific contour, such as a patient's or user's body, in a first programming, but can then be easily donned and doffed by applying a second set of conditions that lead to a second state that allows easy removal and then return to the adapted contour, also referred to shape

change effect. The ability to reprogram to a different contour opens up the possibility of adapting the garment including the 2W-SMT to a different user or part of the user as well as individually adjust compression pressure, as well as its application in sports and leisure garments, where muscle exertion and the need for support are significant, as well as for recovery, which can be enhanced by individualized compression of the muscle.

[0021] The two-way covered shape memory polymeric fiber (2W-cSMPF) comprised by the textile of the invention solves the mechanical problems associated with shape memory effects of previous shape memory fibers, such as insufficient shape recovery and deformation fixation efficiency for practical textile applications, particularly in functional clothing and/or garments used in medical, recreational, and technical applications. It also addresses the further associated problems encountered with two-way shape memory materials which have at least three sets of states exhibiting different tensile properties and having different associated elastic limits on their stress-strain curve. The cover element solves this problem by providing a limiting cover element, in particular a covering yarn or covering fiber, that limits overstretching in the second state (S_2), which is the state with the highest relative and/or absolute elongation in relation with the base state (S_0) strain and therefore can be subject to irreversible damage from overstretching.

[0022] This enables the use of shape memory materials in textiles and fabrics to be made into garments that can be used in medical, leisure, and technical applications. One of the key advantages of the 2W-cSMPFs in this disclosure is their ability to maintain consistent shape fixation and recovery over multiple shape memory cycles. This is critical in medical applications where precise and reliable performance is required.

[0023] Furthermore, this design limits the maximum extension of the two-way shape memory polymeric fiber (2W-SMPF) comprised by the 2W-cSMPF to a predetermined strain, preventing overstretching and potential structural damage. This limitation is particularly beneficial in medical textiles where controlled compression and consistent support are critical to therapeutic efficacy, especially when constant and reproducible pressures are required for effective treatment.

DETAILED DESCRIPTION

[0024] The present invention relates to a **two-way shape memory textile** (2W-SMT), in particular for use in functional or therapeutic garments, comprising or consisting of:

a) a base fabric formed from a plurality of base fibers, wherein the base fabric comprises a shape memory area, and wherein the base fabric is

adapted to a surface contour,

b) wherein the shape memory area comprises or consists of one or more two-way covered shape memory polymeric fiber(s) (2W-cSMPFs), in particular a plurality of 2W-cSMPFs integrated with or intertwined in the base fabric, the 2W-cSMPF comprising

- a two-way shape memory polymeric fiber (2W-SMPF) having at least a base state (S_0), a first (S_1), and a second programmed state (S_2), and
- the 2W-cSMPF is switchable between the base state (S_0) and a programmed state (S_1/S_2) by an external stimulus (E_0) and between the first programmed state (S_1), the second programmed state (S_2) and vice versa by a further external stimulus (E_1/E_2), and
- a covering element, preferably a covering yarn or covering fiber, wound around the 2W-SMPF,

c) wherein in the first programmed state (S_1) of the 2W-cSMPF, the contraction or expansion, i.e. size change, of the 2W-cSMPF induces a corresponding size change of the shape memory area of the base fabric, preferably by 5% to 200%, wherein the ratio between size change of the 2W-cSMPF and corresponding size change of the shape memory area is preferably between 0.5 and 1.5, wherein

the covering element limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF in first programmed state (S_1) and/or second programmed state (S_2), preferably the first and second programmed state (S_1/S_2), to a value between 100% and 800%, more preferably 100% and 600%, most preferably 200% and 500%, and particularly preferably below the elastic limit (ϵ_{elast}), most particularly preferably below the elongation at break (ϵ_{break}) of the 2W-SMPF, and

the base fabric is contracted or expanded, in particular in a state without external stress, in the shape memory area by the 2W-cSMPF in the first programmed state (S_1), preferably by 2.5% to 200%, more preferably 3.5% to 150%, most preferably between 5% and 125%, in comparison with the second programmed state (S_2).

[0025] This two-way shape memory textile (2W-SMT) has a number of advantages over the state of the art: When designed as a three dimensional fabric, also referred to as garment, by comprising a covered two-way covered shape memory polymeric fiber in the shape memory area provides a controlled and defined com-

pression pressure, preferably between 0.5 and 8.5 kPa at the surface contour, such as a subject's body, in the first programmed state (S_1) which is adapted to the specific surface contour. It also allows for flexible donning and doffing by applying a further external stimulus (E_1/E_2) which leads to a second programmed state (S_2) which provides a reduced compression pressure and/or leads to an expansion, in particular in stress free conditions, of the two-way shape memory polymeric fiber (2W-SMPF). Additionally, an irreversible damage to the two-way shape memory polymeric fiber (2W-SMPF), either in the first and/or second programmed state (S_1/S_2) by overstretching the 2W-SMPF is limited by the covering element which limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF in first programmed state (S_1) and/or second programmed state (S_2) to a value between 100% and 800%, more preferably 100% and 600%, most preferably 200% and 500%, and particularly preferably below the elastic limit (ϵ_{elast}), most particularly preferably below the elongation at break (ϵ_{break}) of the 2W-SMPF. It also acts as the first layer of the 2W-SMPF, protecting the fiber from frictional damage and potentially increasing compatibility with the base fiber of the 2W-SMT. These properties, as well as the further, more specific embodiments, lead to a synergistic improvement of the textile provided by combining and adapting the specific components in the manner described. By providing a customized 2W-cSMPF with the properties disclosed herein as part of the 2W-SMT, the inventors offer a significant improvement over the prior art, in particular due to the programming by the external stimulus (E_0), which enables the conversion to a programmed state that is adapted to the surface contour or allows easy application of the 2W SMT and is switchable between two defined programmed states (S_1/S_2) by one or two further external stimuli (E_1/E_2), preferably two different stimuli.

[0026] In some preferred embodiments, especially those related to the use as a compression garment, the 2W SMT provides a compression pressure to the surface contour, wherein the compression pressure exerted by the 2W SMT in the second programmed state (S_2) is lower than the compression pressure in the first programmed state (S_1), preferably between 10% and 100%, wherein 100% equals to an compression pressure of 0 kPa. This allows easy donning and doffing of the textile and is caused by the contraction and/or expansion of the 2W-cSMPF by switching between the programmed states S_1 and S_2 by an external stimulus E_1 and/or E_2 .

[0027] In the context of the present invention, a two-way covered shape memory polymeric fiber (2W-cSMPF) comprises of

- a) a two-way shape memory polymeric fiber (2W-SMPF) (3.1), having at least a base state (S_0), a first (S_1), and a second programmed state (S_2),

- b) the 2W-cSMPF (3.0) is switchable between the base state (S_0) and a programmed state (S_1/S_2) by an external stimulus (E_0); and between the first programmed state (S_1), the second programmed state (S_2) and vice versa by a further external stimulus (E_1/E_2), and

- c) a covering element (3.2) wound around the 2W-SMPF (3.1), wherein the covering element (3.2) limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF (3.0) in first programmed state (S_1) and/or second programmed state (S_2) to a value between 100% and 800% and below the elongation at break (ϵ_{break}) of the 2W-SMPF (3.1), preferably determined at 10°C, and wherein the 2W-cSMPF (3.0) is contracted or expanded by the further external stimulus (E_1/E_2), preferably by 2.5% to 200%

[0028] This has the advantage that 2W-cSMPF exhibit consistent shape stability and recovery over multiple shape memory cycles and ensure a wide stretchability range while maintaining shape memory properties. This is critical for a wide range of textile applications where precise and reliable performance is required. The second state (S_2), which is associated with a greater expansion and/or elongation than the first state (S_1), is typically the state of the 2W-SMPF which is most vulnerable to damaging due to stretching beyond a limit, such as the elastic limit (ϵ_{elast}) or elongation at break (ϵ_{break}). Thus, the covering element is used and especially configured to limit the stretchability or deformation of the core two-way shape memory polymeric fibers (2W-SMPF) during programming so as to ensure maximum recoverable strain.

[0029] In some preferred embodiments, during the first set of external stimuli (E_1), the 2W-SMPF is stretched beyond the elastic limit (ϵ_{elast}) while being programmed from the base state (S_0) to a programmed state. This may be necessary for providing the conditions for the 2W-SM Effect, which is a plasticity-based effect. In these embodiments, the covering element is either applied after the programming in the manufacturing process, or the covering element is wound around the 2W-SMPF in such a manner that the resulting 2W-cSMPF may be stretched beyond the elastic limit (ϵ_{elast}) of the base state (S_0), but limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF in first programmed state (S_1) and/or second programmed state (S_2) to a value between 100% and 800%, more preferably 100% and 600%, most preferably 200% and 500%, and particularly preferably below the elastic limit (ϵ_{elast}), most particularly preferably below the elongation at break (ϵ_{break}) 2W-SMPF. This allows the programming of the fiber in the base state (S_0) while protecting the 2W-cSMPF as well as the 2W-SMT comprising it during application.

[0030] In some preferred embodiment, the covering element, preferably a covering yarn or covering fiber, is

wound around the 2W-SMPF in a manner that limits the strain, preferably the maximum strain ($\epsilon_{\max}$), of the 2W-cSMPF (3.0) to at most the strain at the elastic limit (ϵ_{elast}) of the 2W-SMPF (3.1) in the second programmed state (S_2). This reduces the risk of overstretching the 2W-SMT during the typically most extended state (S_2), which is characterized by the longest comprised 2W-cSMPF(s) and the lowest compression pressure provided on a surface contour.

[0031] In some alternative preferred embodiments, the maximum strain ($\epsilon_{\max}$) of the 2W-SMPF, preferably in the first or second programmed state (S_1/S_2), comprised by the two-way covered shape memory polymeric fiber (2W-cSMPF) is limited to a percentage of the elongation at break (ϵ_{break}), preferably between 20% and 90% of the uncovered 2W-SMPF, preferably determined at 10 °C, wherein the percentage of the maximum strain ($\epsilon_{\max}$) is in the numerical range obtained by combining any two of the following end point values: 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90% of the elongation at break (ϵ_{break}). This limits the risk of ruptures due to overstretching and extends the lifetime of the 2W-SMT textiles and garments.

[0032] A "fiber" in the context of this invention is a single continuous strand of a material, a form in which it is much longer in one axial direction than in two other comparably small directions. In some preferred embodiments, a fiber in the spirit of the current invention is a staple fiber, i.e. a fiber of discrete, finite length that is significantly shorter than the total length of any spun yarn composed of such fibers, such as cotton or wool yarns.

[0033] A "filament" according to the current invention may be a monofilament, which corresponds to a "fiber" in the spirit of the current invention, or a multifilament, which comprises at least a "fiber" in the spirit of the current invention. A multifilament is a bundle of co-directed fibers that in some preferred embodiments are filament fibers, i.e. fibers whose length is comparable to the length of the multifilament, such as synthetic textile yarns.

[0034] A "surface contour" refers to the two or three-dimensional external geometry or boundary of a surface or an object, preferably a subject, in particular of a human, which is defined by the shape and curvature of the object. In a preferred embodiment, the surface contour is characterized by measurable parameters including curvature, convexity, concavity, and specific anatomical landmarks, thereby providing a quantifiable reference for garment adaptation and compression application.

[0035] A "base fabric" means any textile material, in particular woven, knitted, or non-woven structures, which serves as the primary substrate for the incorporation of functional elements. Preferably, the base fabric is engineered to be dimensionally stable in at least two dimensions and adaptable to a predetermined

surface contour, thereby providing an adaptable support structure wherein shape memory areas can be defined and integrated.

[0036] A "base fiber" as disclosed herein is any fiber suitable and used in the production of textiles, including synthetic, natural and semisynthetic fibers. Preferably, the base fiber is integrated into the base fabric such that it provides a base for the integration of 2W-cSMPFs, such that the collective mechanical properties of the fiber mesh (fabric) can be configured according to the required parameters, which can be configured by the fiber properties, the mesh geometry, and the density of the base fibers in the base fabric, the geometric arrangement, the interlacing method, properties and density of the 2W-cSMPFs in the base fabric. In some preferred embodiments, the 2W-cSMPFs are integrated such that a change in size of the fibers, in particular a contraction or expansion, results in a corresponding change in size in the shape memory region of the 2W-SMT, which is achieved by the operative connection between the 2W-cSMPFs and the base tissue in these regions, preferably with a ratio of 0.5 to 1.5 between the change in size of the 2W-cSMPFs and the 2W-SMT.

[0037] In some embodiments, these fibers are preferably selected from the list consisting of cotton, wool, silk, linen, viscose (rayon), polyether-polyurea copolymer (elastane), acrylic, polyamide, such as nylon 66 (PA 6.6) or polycaprolactam (PA 6), polyester fibers, or a blend thereof.

[0038] In some alternative embodiments, said fibers are selected from specialty fibers such as aramid, polybenzimidazole (PBI), polyoxazole (PBO), which are strong synthetic fibers used in specialized applications.

[0039] A "compression pressure" refers to the mechanical force or pressure, in particular generated by the activated shape memory components, that is exerted inwardly onto a subject's surface contour. Preferably, it is produced by the contraction of the shape memory area and is quantitatively expressed as a pressure (e.g., kilopascals), and is sufficient to yield a therapeutic or supportive effect upon the subject. The compression force exerted by the 2W-SMT in the first programmed state (S_1) is preferably in the range of 0.05 to 15 kPa, more preferably between **0.1 and 10 kPa**, most preferably between 0.5 and 8.5 kPa. This allows for the use of the 2W-SMT, especially in the first programmed state (S_1), in therapeutic as well as leisure applications.

[0040] A "contraction or expansion", also referred to as a "size change", refers to a controlled, quantifiable reduction or increase in at least one dimension of the textile, preferably at least two dimensions, most preferably in three dimensions, in particular within the shape memory area, as a direct result of the external stimulation of the 2W-cSMPF(s). Preferably, contraction or expansion is characterized by a percentage decrease or increase in size, respectively, in linear or surface dimensions relative to an initial reference state. If the size

change is a contraction, this leads to the generation of a compression pressure when the textile is applied to an object, more preferably in the range of 5% to 200%. In case of an expansion, it leads to the corresponding relief of such a compression pressure. In one dimension, e.g., in the context of a 2W-cSMPF or a bundle thereof, a size change refers to a change in strain and/or stress, in two dimensions to the simultaneous change in strain in the arrangement of 2W-cSMPF(s) in the 2W-SMT. A typical three-dimensional application is a connected surface formed from a two-dimensional fabric. Therefore, the change in strain can be determined by cutting out a substantially two-dimensional portion of the three-dimensional fabric and determining the change in strain and/or stress of the fibers contained therein.

[0041] In some preferred embodiments, the contraction or expansion (size change) may be determined by cutting apart a 2W-SMT into the individual comprised fibers and determining the reversible change in length (ϵ'_{rev}) of the 2W-cSMPF(s) comprised therein, preferably with a tensile testing machine.

[0042] A "shape memory area" means one or more designated region(s) of the base fabric, in particular an area configured to incorporate or comprise 2W-cSMPF(s). Preferably, this area is configured to undergo reversible transitions between at least two programmed states by the 2W-cSMPF(s) comprised therein, thereby enabling controlled contraction and relaxation that adapts the textile to the surface contour of an object while providing a defined compression pressure.

[0043] A number of different techniques are known in the state of the art to integrate different fibers and fabrics to create textiles. In the spirit of the current invention, any technique adapted to form an interconnection of 2W-cSMPFs with a base fabric and/or the base fiber of the 2W-SMT is suited for providing a 2W-SMT according to the current invention.

[0044] The term "interwoven" in the spirit of the invention refers to the method of arranging fibers, in particular 2W-cSMPF(s) of the invention, by systematically crossing them over and under each other. This weaving process, for example as defined by ISO 3572:1976, creates a fabric or mesh network where the 2W-cSMPF(s) intersect at regular intervals, forming a grid-like structure. In an interwoven design, the 2W-cSMPF(s) can be aligned in perpendicular or other angular arrangements to create various weave patterns. The interweaving of 2W-cSMPF(s) ensures a uniform distribution of the shape memory effect throughout the fabric, allowing for consistent performance and functionality.

[0045] The term "intertwining" in the spirit of the invention involves twisting or entangling 2W-cSMPF(s) together without following the systematic over-and-under pattern of weaving. Intertwined 2W-cSMPF(s) create a fabric where the fibers are looped or knotted around each other, forming a network that retains the

shape memory properties while allowing for more flexibility and adaptability in the textile's design.

[0046] In both interwoven and intertwined arrangements, the 2W-cSMPF(s) comprised by the 2W-SMT form an operatively connected structure. This structure is akin to a mesh network or fabric, where each individual fiber contributes to the overall shape memory functionality of the textile. The operative connection means that the movement or deformation of one fiber affects and is coordinated with the surrounding fibers, enabling the entire textile to exhibit the desired shape memory properties uniformly.

[0047] A person skilled in the art of textile manufacturing would understand various methods of arranging fibers to create these operatively connected structures. Techniques such as knitting, weaving, braiding, and knotting can be employed to form shape memory fabrics. The choice of technique depends on the desired properties of the final product, such as flexibility, stretchability, strength, and the specific shape memory characteristics required.

[0048] Additionally, in some preferred embodiments, a 2W-SMT in accordance with the current invention is configured as a shape memory inlay. This involves embedding or integrating the 2W-cSMPF(s) within a base fabric formed by the base fiber, preferably a non-shape memory base fabric. The inlay technique allows for the incorporation of shape memory properties into conventional fabrics, enhancing their functionality. This integration can be achieved in a specific knitting process as well as through sewing, adhesive bonding, or other methods known to those skilled in the art.

[0049] Furthermore, the present invention relates to a shape memory textile (2W-SMT) comprising a 2W-cSMPF(s) according to the current invention and at least a base fabric comprising or consisting of a base fiber, preferably non-shape memory fabric, and/or a further fiber, preferably non-shape memory fiber, wherein the cSMPF is arranged in and/or on the base fabric, therefore yielding the 2W-SMT, by textile manufacturing processes known by the person skilled in the art, preferably selected from but not limited to the list consisting of knitting, preferably circular knitting or flat knitting or jacquard knitting, weaving, preferably inlay weaving or layered weaving, braiding, embroidery, composite techniques, 3D textile structure inclusion or as weft or warp yarn. This configuration ensures that the structural integrity and the shape memory properties of the cSMPF are maintained within the textile, preventing overstretching and potential damage to the fibers.

[0050] In some alternatively preferred embodiments, the base fabric is formed by integrating 2W-cSMPF(s) and base fibers in a single processing step, thus, the base fabric isn't provided in a first step, but created during the textile manufacturing process of the 2W-SMT.

[0051] In the present invention, "knitting" is utilized as

a preferred method for integrating 2W-cSMPF(s) into the 2W-SMT. This technique involves interlocking loops of yarn to create a fabric, which can be executed in various forms. Circular knitting is the preferred method for producing seamless, tubular structures, whereby the knitting is done in a continuous circular motion. This technique can be utilized for the production of items such as socks, tubulars, and other circular garments. Preferably, 2W-SMT(s) for use as compression garments are produced in a circular knitting machine, such as a stocking or sock knitting machine.

[0052] In some further preferred embodiments, single pieces of 2W-SMT(s) produced by circular knitting are cut and sewed together, in particular with non 2W-SMT fabric pieces. The integration of 2W-cSMPF(s) into circular knitting can lead to innovative applications such as tubular compression garments with shape memory properties.

[0053] "Flat knitting" involves knitting back and forth in rows, allowing for more intricate designs and patterns. Flat knitting is suitable for the production specialized patterns and may be utilized in conjunction with shape knitting techniques to produce a variety of 2W-SMT fabrics. Preferably, these may that can be cut and sewed and combined with different fabrics into specific garments. This application is particularly useful for expensive fibers, such as the 2W-cSMPF(s) of this invention, where the fibers used have a greater influence than the production time. The use of 2W-cSMPF(s) in flat knitting can result in shape memory fabrics with complex geometries and detailed designs. As a specialized form of knitting, Jacquard knitting allows for the creation of multi-colored and complex patterns.

[0054] "Embroidery", as applied in this invention, involves the decorative and/or functional stitching of 2W-cSMPF(s) onto a base fabric. This technique allows for precise placement of 2W-cSMPF(s), enabling the addition of shape memory functionalities in specific patterns or designs. Embroidery can be used to create localized regions of shape memory properties, which can add functional value, such as adaptive fit or dynamic structural support in specific areas of the textile, for example in sport and leisure garments as well as specialized medical applications, for example individual burn and scar dressing.

[0055] "Composite techniques" refer to the combination of 2W-cSMPF(s) with other materials to form a composite 2W-SMT. This approach can involve layering, bonding, or embedding 2W-cSMPF(s) with other fabrics or materials to enhance the overall properties of the 2W-SMT. The result is a synergistic combination where the shape memory properties of the 2W-cSMPF(s) are integrated with the structural, thermal, or other characteristics of different materials. Composite techniques are particularly useful in applications requiring a balance of flexibility, strength, and adaptive shape memory functions.

[0056] "Braiding" involves intertwining multiple

strands of 2W-cSMPF(s), and possibly other types of fibers, preferably the base fiber, in a systematic pattern. This method provides a unique way to create strong, flexible, and durable textiles with shape memory properties. Braided structures are particularly suited for applications requiring high tensile strength and resilience, such as in medical devices, protective clothing, or in structural applications where the shape memory effect can be utilized for dynamic functionality. The braiding process allows for the creation of complex, three-dimensional textile structures with enhanced shape memory characteristics.

[0057] Additionally, the present invention relates to a method for producing a 2W-SMT, comprising the steps of

a) Providing 2W-cSMPF(s), then

b) Arranging the 2W-cSMPF(s) into and/or onto the base fabric, alternatively preferably directly with the base fiber, preferably by knitting, particularly preferably circular knitting or flat knitting or jacquard knitting, weaving, particularly preferably inlay weaving or layered weaving, braiding, embroidery, composite techniques, or 3D textile structuring.

[0058] By selecting and combining different techniques for arranging the cSMPF, a wide range of textiles and fabrics with customized shape memory properties can be created. This approach allows for the use in various applications, from clothing and accessories to medical devices and industrial materials and the provision of specialized garments, such as compression garments.

[0059] Also disclosed by the current invention is a use of the covered shape memory polymeric fiber in a textile, preferably a shape memory textile, such as a technical, medical, orthopedic, industrial, sports or leisure textile.

[0060] In a preferred embodiment the 2W-SMT is specifically tailored for individuals at suffering from or at risk from suffering from conditions such as poor circulation, edema, or varicose veins, and/or support during post-surgical recovery. The garment features graduated compression to enhance blood flow, normalize blood backflow, reduce swelling, and improve overall comfort.

[0061] Another embodiment is focused on athletes and sports enthusiasts. This version of the 2W-SMT is engineered to support muscle recovery, reduce fatigue, and enhance athletic performance. It incorporates materials and designs suitable for high-intensity activities and endurance sports. The garment is optimized for performing activities such as swimming, skiing, running, cycling, and team sports, where muscle exertion and the need for support are significant, as well as for recovery, that can be enhanced by individualized compression of the muscles.

[0062] Another embodiment of the 2W-SMT are applications of compression therapy where highly individualized garments and/or bandages are required for each individual case. In these applications, deformation of the patient's body or prescribed therapy demand individual fit and/or compression profile, for example in treatment of burns, scars, or ulcers, as well as developed stages of conditions such as edema.

[0063] In the context of this invention, the 2W-cSMPF comprises a two-way shape memory polymer (2W-SMP), which, in addition to the 1W-SM effect, has a base state S_0 , which may be programmed by an external stimulus (E_0) into one of the at least two different sets of programmed states (S_1/S_2) which can be mutually switched by applying a further external stimulus (E_1/E_2), wherein the external stimulus (E_1/E_2) refers two different sets of conditions which are able to trigger a change of state or phase transition in the 2W-cSMPF. Here, the external stimulus E_0 is responsible for transitions between S_0 and S_1 , while the external stimulus E_1 and/or E_2 is responsible for reversible transitions between the programmed states S_1 and S_2 . A stimulus (E_1/E_2) may also be the "absence" of such a stimulus, for example the removal of heat and cooling the textile back to room temperature, the switching off/ turning on an external magnetic field source or power source, this is also referred to as $-E_1$ to denote the to indicate the contrasting character to E_1 . 2W-SMPs, such as those comprised by the 2W-cSMPF and 2W-SMT comprise at least two phases or domains triggered by different activation conditions, consisting of different switching segments or components with different transition or switching conditions, preferably selected from the list consisting of thermal, electromagnetic, electric, or light stimulation. This allows to store two temporary shapes, also referred to as first and second state (S_1/S_2) in their "shape memory" (SM) in addition to their permanent shape, also referred to as base state (S_0).

[0064] "Programming" or "programmable" refers to the process or property of changing the fixing the shape and state (S_0 , S_1 , S_2), in particular the transition from base state (S_0) to the first or second programmed state (S_1/S_2), of a covered shape memory polymeric fiber (2W-cSPMF) comprising a 2W-SMPF comprising or consisting of a shape memory polymer by application of a set of external conditions, in particular an external stimulus (E_0). The shape and properties of a shape memory polymer can be changed by rearranging the crystalline rigid segments and the switching segments and then equilibrating them. The programming can be achieved with thermal, electromagnetic, electrical or light stimulation. In addition, the reversible changes between the programmed states S_1 and S_2 are shape change effects, which are archived by a further stimulus (E_1/E_2).

[0065] Preferably, in addition to thermal, electromagnetic, electrical or light stimulation, a further component may be added, typically a defined force F as part of an

external stimulus ($E_0/E_1/E_2$), which leads to a controlled elongation or strain during programming or the shape change.

[0066] A "thermally programmable", in particular "thermal programming" shape memory polymer can be programmed by a specific thermic programming process. An electrically or magnetically programmable 2W-cSMPF may be also regarded as a "thermally programmable" shape memory polymer, but the thermal stimulation is produced in situ by electric resistance (electric heating) by applying an external electric current as external stimulus ($E_0/E_1/E_2$) or by electromagnetic heating by magnetic particles or nanoparticles comprised by the 2W-cSMPF and magnetic stimulation by an alternating magnetic field applied as an external stimulus ($E_0/E_1/E_2$).

[0067] In some preferred embodiments, the base state allows for easy application of the 2W-SMT to a surface contour. The programming stimulus (E_0) then triggers a shape transition (phase change) of the 2W-SMP to a programmed state (S_1/S_2). The further external stimulus (E_1/E_2), which is different to the programming stimulus, then triggers a second shape transition (phase change) of the 2W-SMP to the second programmed state (S_2) and vice versa.

[0068] In alternative preferred embodiments, the 2W-SMT in a base state (S_0) is programmed under an external stimulus (E_0) to allow fitting to a surface contour, by expanding the 2W-cSMPF(s) comprised by the 2W-SMT, and reaching the programmed state S_2 . The size, for example the circumference, of the 2W-SMT in the initial state (S_0) is smaller than in the second programmed state (S_2), so that the initial programming makes it possible to expand the 2W-SMT to a size that is suitable for putting the garment on.

[0069] An "external stimulus", also referred to as a "stimulus", refers to a specific and defined set of external conditions, which trigger a shape transition (phase change) of the 2W-SMP comprised by the 2W-cSMPF of the 2W-SMT of the current invention. The process of external stimulation, in particular the application of an external stimulus (E_0), is referred to as "programming", which refers to the duration and manner in which the external stimulus is applied, while the application of a further external stimulus (E_1/E_2) may also referred to as shape change effect.

[0070] In a preferred embodiment, the external stimulus (E_0) and further external stimuli (E_1/E_2) are selected from the same type of activation, preferably selected from the list consisting of thermal, electromagnetic, electrical or light stimulation, wherein the external stimulus (E_0) and further external stimuli (E_1/E_2) have a different set of conditions in their respective stimulation. This includes different magnetic field strengths or field modulations/orientations, different wavelengths or light intensities, different, separated temperature ranges or electrical characteristics such as repetition frequency, intensities. This can be programming from the ground

state (S_0) to the first or second state (S_1/S_2) and reversible switching between these states using the same applicator or stimulus source, such as an internal or external thermal source. An internal thermal source can be, for example, the combination of a magnetic field generating coil or current source with an electrically conductive or magnetically active 2W-cSMPF integrated into the 2W-SMT. An external thermal source can be designed as a heater or a cooling mechanism.

[0071] In some alternatively preferred embodiments, the external stimulus (E_0) and further external stimuli (E_1/E_2) are independently selected from different types of stimulation, preferably selected from the list consisting of thermal, electromagnetic, electrical, or light stimulation, wherein the external stimuli ($E_0/E_1/E_2$) have a different set of conditions in their respective stimulation. This allows for more precise stimulation and can prevent accidental reprogramming of the first state (S_1) as well as S_1/S_2 codependence, for example by applying a higher temperature than intended. For example, the external stimulus (E_0) would be a thermal stimulus with a force F that generates a specific strain, such as programming during the production of the 2W-cSMPF, for example during extrusion or during a subsequent cross-linking reaction, transfers the 2W-SMT from the ground state (S_0) to the second programmed state (S_2). Then, in a second step, the 2W-SMT in the second state (S_2), which is larger than the surface contour of the body of a test subject, would be programmed by a further external stimulus (E_1), for example an alternating magnetic field, and transferred to the first state (S_1) to contract the 2W-cSMPF in the shape memory area of the 2W-SMT, thereby generating a specific compression pressure. By applying a different further external stimulus (E_2), for example cooling (lower temperature), the 2W-cSMPF is converted into a new phase corresponding to the first programmed phase (S_1) and the compression pressure is released, allowing the 2W-SMT to be easily put on and/or taken off. This cycle is reversible, allowing the 2W-SMT to be used in a variety of applications.

[0072] In a preferred embodiment, the further external stimulus (E_1/E_2) for reversibly switching between the first programmed state (S_1) and the second programmed state (S_2) could comprise a first set of conditions (E_1) as well as an opposing second set of conditions ($-E_1$). The external stimulus E_1 could be, for example, thermal activation, caused by and external magnetic field, direct thermal activation or electric current, resulting in a contraction of the 2W-cSMPFs of the 2W-SMT, which correlates to a change from S_2 to S_1 , thereby creating a compression pressure. Then, the opposing set of conditions ($-E_1$) of the external stimulus is provided, preferably comprising restoring the initial temperature conditions, or cooling the 2W SMT below a certain threshold, preferably below 10°C , more preferably below 0°C , most preferably below -10°C , resulting in expansion of the 2W-cSMPFs and reducing

the compression pressure. Depending on the circumstances, $-E_1$ and E_2 may be identical.

[0073] In a preferred embodiment, the 2W-SMT is programmed from the base state (S_0) to the first state (S_1) according to the contours of a patient's body. That is, the 2W-SMT or fabric is adjusted to conform to the patient's specific body shape (S_1) by applying an external stimulus (E_0). When worn and removed by applying a further external stimulus E_1 (or E_2), the 2W-SMT changes shape and/or compression pressure by changing to the second programmed state (S_2), which has a greater expansion. The process is reversible, by applying another further external stimulus ($-E_1/E_2$), the first programmed state (S_1) and shape can be restored. This is particularly useful in medical and/or sports garments where a customized fit is essential for therapeutic effectiveness.

[0074] In some alternatively preferred embodiments, this procedure is reversed and the 2W SMT is programmed by an external stimulus (E_0) to a size larger than the surface contour, corresponding to the second programmed state (S_2), to allow easy donning. Then, a further external stimulus (E_1) is applied to contract the 2W-SMT to the first programmed state (S_1) to achieve an optimal fit and, preferably, a compression pressure. This process is also reversible by a complementary further external stimulus ($-E_1/E_2$).

[0075] In some embodiments, the conditions, such as electric field strength, electric current and voltage, and temperature range of the external stimulus (E_0) and/or further external stimuli (E_1/E_2), more preferably E_1 and E_2 , is selected such that the programming and/or shape recovery can be performed directly on the body surface contour of a subject, preferably a human. This may advantageously allow the programming to a programmed state S_1 and S_2 corresponding and recovery of the 2W-SMT comprising a 2W-cSMPF directly to the subject's shape and realize an optimal force distribution such conditions are detailed below:

In some preferred embodiments of the present invention, the external stimulus (E_0) and further external stimuli (E_1/E_2) are thermal stimuli having a programming temperature (T_{prog}) in the range between -20 and 90°C , as for example determined with an optical IR thermometer, wherein the further stimuli (E_1/E_2) are separated by a temperature difference (ΔT) of at least 40°C , preferably at least 30°C , more preferably at least 20°C . Alternatively preferably, the temperature difference (ΔT) is in the range between 5°C and 60°C , preferably between 10°C and 50°C , more preferably between 10°C and 40°C . This allows the reversible and controlled switching between the first (S_1) and second programmed state (S_2) of the 2W-SMT and the comprised 2W-cSMPF and reduces the possibility of an accidental switch.

[0076] In some particularly preferred embodiments, the further external stimuli E_1 and E_2 are thermal stimuli in a range of -20°C to 70°C , preferably -10°C and 60°C ,

as for example determined with an optical IR thermometer. This allows programming directly on the surface contour of a body of a subject, preferably of a human. The base fabric and the 2W-cSMPFs may provide a layer of protection against the more extremes end points of the preferred range and thus allowing donning and doffing without causing pain or discomfort to a user during the programming.

[0077] In some preferred embodiments, external stimulus (E_0) and/or further external stimuli (E_1/E_2), more preferably the external stimuli E_1 and/or E_2 , is/are an electrical stimulus, the applied external voltage is in the range of 10 to 110 V, as preferably determined with a voltmeter. This allows for use within the range of the domestic supply voltage. In some further embodiments, the electrical stimulus has a voltage in the range of 1 to 40 V, more preferably between 1 to 20 V which allows for use on a person's body, with the body's own resistance protecting against electric shock.

[0078] In some preferred embodiments, the external stimulus (E_0) and/or further external stimuli (E_1/E_2), more preferably the external stimuli E_1 and/or E_2 , is/are is an magnetic stimulus, the applied magnetic field strength (H) is in the range of 5 and 50 kA·m⁻¹, preferably 5 and 30 kA·m⁻¹, preferably determined with a magnetometer.

[0079] "Strain" as used herein, is a dimensionless quantity (given as a percentage) and refers to the relative deformation (%) of a fiber, in particular a base fiber, covering element, 2W-SMPF and/or 2W-cSMPF, under stress expressed as the ratio of the change in length to the original length of the fiber, wherein the original length refers to the base length of a 2W-cSMPF in a specific state, such as base state, first programmed and second programmed state (S_0 , S_1 , S_2). Elongation refers to a similar concept, and can be expressed as absolute change in length, but is herein also used as a relative deformation of a fiber and may be used interchangeably.

[0080] "Stress" refers to the force applied per unit cross-sectional area of a fiber, in particular a base fiber, covering element, 2W-SMPF and/or 2W-cSMPF. It quantifies the internal load a material experiences when external forces are applied.

[0081] In the spirit of the current invention, the "elastic modulus" (E), also referred to as "Young's modulus", quantifies the relationship between tensile or compressive stress σ (force "F" per unit area "A") and axial strain ε (proportional deformation) in the linear elastic region as following:

$$E = \frac{\sigma}{\varepsilon}$$

[0082] In some preferred embodiments of the 2W-cSMPF, the elastic modulus (E), also referred to as Young's modulus, preferably determined at 25 °C, is between 1.0±0.5 and 15.0±0.5 MPa, preferably be-

tween 2.0±0.5 and 10.0±0.5 MPa, more preferably between 2.0±0.5 and 4.0±0.5 mPa. This allows for a broad range of applications where different stress and strains are required.

[0083] In the present disclosure, the maximum deformation of the 2W-SMPF of a given length (L_0) and diameter (D_0) in the unstretched state by covering the 2W-SMPF with a covering element can be influenced by the density of entwining (also preferably referred to as density of covering) (ρ_0) of the 2W-SMPF in the unstretched state, i.e. by the number of twists per meter of the covering element when the 2W-SMPF is in the unstretched state, and the length (l) and diameter (d) of the covering yarn, all in relation to the diameter of the 2W-SMPF (D_0) in the unstretched state. Upon applying a stress to the 2W-cSMPF so as to stretch the fiber, the length (L_1) of the 2W-SMPF increases, whereas the density of entwining (ρ_1) decreases. The strain (ε) of the 2W-SMPF is given by the following formula:

$$\varepsilon_1 = \frac{L_1 - L_0}{L_0} \times 100\%,$$

wherein ε_1 is the strain, L_1 is the length of the 2W-SMPF at said stress, L_0 is the length of the 2W-SMPF in the unstretched state.

[0084] The "elastic limit" ($\varepsilon_{\text{elast}}$) in the spirit of the current invention is the point on a stress-strain curve that indicates the limit of elastic behavior. The elastic limit, especially in the context of the shape memory polymers comprised by the 2W-SMPF of the 2W-cSMPF may be determined by thermomechanical analysis using a tensile testing machine, for example an MTS 858 testing machine equipped with an appropriate indirect temperature measurement system, preferably an IR camera, for example a ThermoCam™ Phoenix. An exemplary procedure is described in "Experimental and numerical investigation of yielding phenomena in a shape memory polymer subjected to cyclic tension at various strain rates" (E.A. Piecyszka, M. Staszczak, K. Kowalczyk-Gajewska, M. Maj, K. Golasinski, S. Golba, H. Tobushi, S. Hayashi, Polymer Testing, Volume 60, 2017, Pages 333-342, ISSN 0142-9418, doi:10.1016/j.polymertesting.2017.04.014). The importance of distinguishing between elastic and plastic deformation regions lies in understanding the material's behavior under stress. The elastic regime typically indicates reversible deformation, whereas the plastic regime signifies permanent deformation.

[0085] In some embodiments of the current invention, the elastic limit may be exceeded as part of the external stimulus (E_0) to program the 2W-cSMPF(s) from the base state (S_0) to a programmed state. In some embodiments, the programmed states (S_1/S_2) are therefore in a region between the elastic limit ($\varepsilon_{\text{elast}}$) and the elongation at break ($\varepsilon_{\text{break}}$) of the 2W-SMPF comprised by the 2W-cSMPF. This allows the integration of a 2W-SM while protecting the fibers from breaking under

stress during use.

[0086] In the context of 2W-SMPFs and 2W-cSMPFs mechanical properties of the fiber, such as the elastic limit ($\varepsilon_{\text{elast}}$), can be determined with a step-cycle test described and performed in "Strain recovery and stress relaxation behaviour of multiblock copolymer blends physically cross-linked with PLA stereocomplexation" Izraylit, V., Heuchel, M., Gould, O. E., Kratz, K., & Lendlein, A. (2020). *Polymer*, 209, 122984. <https://doi.org/10.1016/j.polymer.2020.122984>. Here, the elastic limit is determined with a step-cycle test. A sample was stretched to a certain strain ε with a constant extension rate. Then, the stress was removed to 0 at the same contraction rate. At each following step the sample was elongated to a higher strain than at the previous one. The cycles were continued until sample rupture. The recovered strain is considered to be the elastic component ε_e of the deformation, while remaining is the plastic component ε_p of the deformation. Elastic limit can be determined a point of sharp increase of the tangent of the $\varepsilon_p(\sigma)$ where σ is the stress value at the stress-strain curve at deformation ε related to ε_p in the particular step in the step-cycle experiment. In the same work, the yield point is defined as a point of the maximum curvature of the stress-strain curve in the region of elastic limit. Preferably, the differences between those points may be neglected in practical applications. Youngs modulus (E) can be defined as a ratio of the stress to strain values in the initial conditionally linear segment of the stress-strain curve.

[0087] Stretching (elongation) of the 2W-SMPF having the covering yarn wound around it causes the pitch (r), i.e. the distance between two loops of the twist, of the covering element around the 2W-SMPF to increase from r_0 to r_1 , whereby the density of entwining (ρ_1) decreases. The covering element is not stretched until up to a maximum strain (ε_{max}) of the 2W-SMPF. Further stretching of the 2W-SMPF beyond the maximum strain (ε_{max}) would require stretching of the covering element as well. Under the premise that the covering element is substantially unstretchable, stretching the fiber beyond the point of maximum strain (ε_{max}) would cause a steep increase in the force required for further stretching or deformation, after this point, the force exerted by the covering element on the 2W-SMPF increases, potentially crushing and damaging the 2W-SMPF until finally a rupture of the covering element will occur.

[0088] According to some embodiments, the point of maximum strain (ε_{max}) of the 2W-cSMPF is independent of the material of the covering element, and solely dependent on the diameter (D_0) of 2W-SMPF, the diameter of the covering element (d) and the density of entwining (ρ_0), wherein the density of entwining (ρ_0) is defined as:

$$\rho_0 = \frac{n_0}{L_0}$$

wherein ρ_0 is the density of entwining, L_0 is the length of the 2W-SMPF in the unstretched state and n_0 is the number of windings of the covering element around the 2W-SMPF in the unstretched state.

[0089] According to some preferred embodiments of the invention, the maximum strain of the two-way shape memory polymeric fiber (2W-SMPF) is dependent on the material of the 2W-SMPF, particularly the shape memory-polymer comprised by the 2W-SMPF, and the diameter (D_0) of the 2W-SMPF, while being limited by accordingly selecting the diameter of the covering element (d) and the density of entwining (ρ_0) and the material of the covering element so that the maximum strain (ε_{max}) of the 2W-cSMPF, determined by the material and diameter of the 2W-SMPF, should be chosen so as to not exceed the strain in first programmed state (S_1) and/or second programmed state (S_2) to a value between 100% and 800%, more preferably 100% and 600%, most preferably 200% and 500%, and particularly preferably below the elastic limit ($\varepsilon_{\text{elast}}$), most particularly preferably below the elongation at break ($\varepsilon_{\text{break}}$) of the 2W-SMPF, preferably as determined by a tensile testing machine or an extensometer.

[0090] The two-way shape memory effect of a 2W-cSMPF as disclosed herein can be quantified by the deformation fixation efficiency (Q_{ef}), which can be calculated according to:

$$Q_{\text{ef}} = \frac{\varepsilon_{S2}}{\varepsilon_{S1}} \times 100$$

[0091] Another parameter for characterization of 2W-cSMPF is the reversible change in length ($\varepsilon'_{\text{rev}}$), as calculated according to:

$$\varepsilon'_{\text{rev}} = \frac{l_{S1} - l_{S2}}{l_{S2}} \times 100$$

[0092] Herein, l_{S2} and l_{S1} are the lengths at S_2 and S_1 respectively in reversibility cycles, while ε_2 is the elongation at S_2 . These properties can be measured in cyclic experiments (performed on a tensile testing machine with a means to provide and control external stimuli such as a temperature chamber or a magnetic/-electric source and measuring device). Such tests consisted of switching between the first and second programmed state (S_1/S_2) of the 2W-cSMPF, for example heating and cooling of the fiber, under stress free conditions between S_1 and S_2 with a defined time interval.

[0093] In some preferred embodiments, the deformation fixation efficiency (Q_{ef}) for the 2W-cSMPF is between 80% and 100%, more preferably between 92.5% and 100%, especially preferably between 95% and 100%. This allows for repeated use in the disclosed applications. In a most preferred embodiment, the shape-recovery ratio for the covered fibers, especially the covered shape memory polymeric fibers, is

above 95% to meet the demand of the RAL-387 standard for medical compression garments, especially preferably the class 2 range with a pressure range between 3.1 and 4.3 kPa.

[0094] To evaluate the long-term shape memory capability 2W-cSMPFs comprised by the 2W-SMT in accordance with the current invention, a test of ~100 shape memory cycles can be performed, demonstrating reversible change in length (ε'_{rev}) and deformation fixation efficiency (Qef) over the course of 100 cycles. Here, for practical reasons and to reduce the time for a cycle, the heating and cooling rates can be reduced to $10^{\circ}\text{C}\cdot\text{min}^{-1}$ and the equilibration times have been reduced to 1 min.

[0095] In a preferred embodiment of the 2W-cSMPF comprised by the 2W-SMT according to the current invention, the covering element comprises or consists of a material is selected from the list consisting of natural materials, such as cotton, wool, silk, linen or bamboo; semi-synthetic materials, such as viscose or lyocell; synthetic materials, such as acrylic, polyester, polypropylene, polyether-polyurea copolymer (elastane), polyamide, such as aramid, nylon 66 (PA 6.6) or polycaprolactam (PA 6); or a blend thereof. In particular, the covering element comprises or consists of a fiber or yarn selected from the list consisting of cotton, wool, silk, linen, viscose, lyocell, polyether-polyurea copolymer (elastane), acrylic, polyamide, such as aramid, nylon 66 (PA 6.6) or polycaprolactam (PA 6), polyester fibers/yarns; or a combination thereof.

[0096] In some preferred embodiments of the 2W-cSMPF comprised by the 2W-SMT, the covering element is an electrically conductive covering element, preferably selected from the list consisting of wire, conductive fiber, nanocomposite filament.

[0097] In some preferred embodiment of the 2W-cSMPF, the covering element can be a selected from a second shape memory polymeric fiber, as long as the covering element limits the strain, preferably the maximum strain (ε_{max}), of the 2W-cSMPF to at most the strain at the elastic limit (ε_{elast}) of the 2W-SMPF in the second state (S_2).

[0098] In another preferred embodiment of the covered shape memory polymeric fiber according to the current invention, the covering element is wound around the 2W-SMPF as single, double or multilayer covering, in particular one to ten layers, with S or Z direction twists.

[0099] Preferably, the diameter of the 2W-SMPF in the 2W-cSMPF is between 50 and $500\ \mu\text{m}$.

[0100] In some preferred embodiments, the diameter ratio between the covering element and 2W-SMPF is in the range from 1:1 to 1:20. A smaller diameter ratio ensures adequate coverage and protection of the 2W-SMPF by the covering element, while larger ratios allow for greater flexibility and adaptability of the 2W-SMPF within the covering.

[0101] In some preferred embodiments, the covering

element is a fiber, preferably designed as a multifilament or a monofilament fiber. However, multifilament fibers are preferred.

[0102] In a preferred embodiment the 2W-SMPF is a multifilament fiber, preferably with a linear fiber density value between 15 and 1 000 dtex, more preferably between 35 and 600 dtex. A multifilament fiber consists of many fine individual filaments that are collected as a single bundle. This structure may have several advantages, such as increased flexibility, increased strength, and improved rupture resistance. In a preferred embodiment, linear fiber density of the 2W-SMPF in the cSMPF is within the numerical range obtained by combining any two of the following end point values: 15 dtex, 20 dtex, 25 dtex, 30 dtex, 35 dtex, 40 dtex, 45 dtex, 50 dtex, 75 dtex, 100 dtex, 150 dtex, 200 dtex, 250 dtex, 300 dtex, 350 dtex, 400 dtex, 450 dtex, 500 dtex, 550 dtex, 600 dtex, 650 dtex, 700 dtex, 750 dtex, 800 dtex, 850 dtex, 900 dtex, 950 dtex, and 1 000 dtex.

[0103] In an alternatively preferred embodiment related to a 2W-SMT, the 2W-SMPF comprised by the 2W-cSMPF comprised by the 2W-SMT is a multifilament fiber with a linear fiber density value between 250 and 750 dtex, more preferably between 300 and 600 dtex. Because of the lower amount of the cSMPF fibers in a shape memory textile according to the current intention, the linear fiber density of the comprised cSMPF is chosen from this range as lower linear fiber densities would lead to a textile with a weak shape memory effect.

[0104] In the context of fibers, "dtex" stands for "decitex" and is a unit of measurement used to express the linear density or fineness of a fiber. It is defined as the mass in grams per 10,000 meters of the fiber.

[0105] In some preferred embodiments the covering element is wound around the 2W-SMPF with a rate of 300 to 6000 twists per meter, preferably 750 to 3000 twists per meter. A higher twist rate ensures that the covering element is securely wound around the 2W-SMPF, providing stability and protection. At the same time, maintaining the twist rate within this range prevents over-constriction of the 2W-SMPF, which could otherwise impede its shape memory functionality.

[0106] In some preferred embodiments, the 2W-cSMPF has a stretchability from 30 to 1000%, preferably 50 to 900%, which corresponds to the maximum strain (ε_{max}) of the 2W-cSMPF. This flexibility in stretchability means the fiber can be used in settings that require either moderate or significant elongation, catering to various functional needs. For instance, higher stretchability might be desired in textiles for sports and leisure, while moderate stretchability could be more suitable for medical or technical applications.

[0107] In some preferred embodiments of the 2W-cSMPF, the elongation at break (ε_{break}) with error margins is in a range between $500 \pm 150\%$ and $1150 \pm 150\%$, preferably between $600 \pm 150\%$ and $1000 \pm 150\%$. This allows a large safety margin after stretch-

ing the fiber beyond the intended strain according to the invention.

[0108] A "shape memory polymer" in accordance with the current invention is preferably a semi-crystalline polymer with at least a rigid segment and a switching segment. The rigid segment, also referred to as the hard segment, is the part of the shape memory polymer that defines the permanent shape of the material by establishing intermolecular interactions. This segment enables the polymer to retain the information of its original shape under various conditions and/or after deformation. The rigid segment can be presented by covalent bonds, molecular entanglement, crystallites, or other molecular interactions.

[0109] The switching segment of the shape memory polymer is responsible for the shape memory behavior of the material. This segment is designed to be responsive to external stimuli, such as temperature changes. When exposed to a specific temperature, also referred to as programming temperature, associated with a phase transition, preferably melting temperature, molecular interactions in the switching segment are disintegrated, and it becomes flexible, allowing the shape memory polymer to be temporarily reshaped under a certain programming strain (ϵ_{prog}) at programming temperature (T_{prog}) followed by a defined equilibration time. Upon removal of the stimulus, the molecular interactions inside the switching segment are restored. This and the relaxation processes fix the material in the programmed shape, which may correspond to the first and/or second programmed shape (S_1/S_2). In stress-free conditions, further subjecting of the material to the external stimulus resulting in heating it to $T_{\text{high}} < T_{\text{prog}}$ will result transition to shape S_2 , while removing of the external stimulus will result in cooling of the material to $T_{\text{low}} < T_{\text{high}}$ and recovery of shape S_1 . Cyclic change between T_{low} and T_{high} will cause cyclic change between S_1 and S_2 respectively. If the programmed material is subjected to external stresses in a way that transition between S_1 and S_2 is not possible, the shape-memory cycles will cause generation of forces, similarly predictable in a repetitive manner. Heating the material to T_{prog} in stress-free conditions will cause the switching segment returning to its original state, governed by the rigid segment, thus reverting the material to its predefined shape. The switching segment can be presented by crystallites or other reversible molecular interactions.

[0110] In a preferred embodiment the shape memory polymer (SMP) comprised by the 2W-cSMPF is selected from the list consisting of semi-crystalline polyesters, preferably polycaprolactone, ethylene-co-monomer-polymers, preferably cross-linked poly[ethylene-co-vinyl acetate] (cPEVA), poly(ethylene-1-octene), poly[ethylene-co-ethyl acrylate-co-maleic anhydride] (PEEAMA), poly[ethylene-co-(methyl acrylate)-co-(glycidyl methacrylate)] (PEMAGMA), di- or multi-block-co-polymers, preferably amorphous multi block cycloali-

phatic polyetherurethane (PEU) consisting of poly(tetramethylene glycol) (PTMEG), 1,4 butanediol (1,4-BD) and methylene bis(p-cyclohexyl isocyanate) (H12MDI), or semi-crystalline ionomers, preferably perfluorosulphonic acid ionomer (PFSA). These classes of shape memory polymers have been shown to be thermally programmable shape memory polymers with different programming temperatures and chemical properties, although they are known to exhibit degradation effects of the shape memory properties associated with strains in excess of the maximum strain and are thus often not recoverable over multiple cycles or can be irreversibly damaged during programming.

[0111] In a preferred embodiment of the current invention, a shape memory polymeric fiber may be a "cross-linked shape memory polymeric fiber". This fiber is characterized by its enhanced structural integrity and improved shape memory properties due to the cross-linking process. The cross-linking within the polymer structure of the fiber is achieved by incorporating a suitable cross-linking agent, as previously defined, which reacts with the polymer chains to create stable cross-links. A cross-linked shape memory polymeric fiber may preferably be a covalently cross-linked polymeric fiber.

[0112] The cross-linked shape memory polymeric fiber may exhibit superior mechanical strength and shape recovery compared to its non-cross-linked counterparts. This is a result of the cross-links acting as junction points within the polymer matrix, influencing the reordering process, and crystallinity of the bulk material. The degree of cross-linking is carefully controlled to balance flexibility and rigidity, ensuring that the fiber can be deformed to a temporary shape and then recover its original shape upon exposure to a specific stimulus, typically a change in temperature.

[0113] In an especially preferred embodiment of the 2W-cSMPF comprised by the 2W-SMT of the invention, the 2W-SMPF comprises or consists of a cross-linked poly[ethylene-co-vinyl acetate] (cPEVA), wherein poly[ethylene-co-vinyl acetate] is formed from a poly[ethylene-co-vinyl acetate] (PEVA), preferably comprising a cross-linker and/or an initiator, for example by curing which preferably takes place under UV, beta or gamma radiation, or thermal treatment.

[0114] "Poly[ethylene-co-vinyl acetate] (PEVA)", also referred to as covalently cross-linked Poly[ethylene-co-vinyl acetate] (cPEVA), in the spirit of the current invention refers to a co-polymer from vinyl acetate and ethene, which is cross-linked by chemical means to form new covalent bonds starting from poly[ethylene-co-vinyl acetate] (PEVA). The cross-linking can be induced by a cross-linker or cross-linking agent. Advantageously, in some embodiments cPEVA may be prepared by blending different poly[ethylene-co-vinyl acetate] polymers, for example PEVAs with a different vinyl acetate content, and cross-linked by adding cross-linking agents and/or initiators and/or by curing.

[0115] In another preferred embodiment of the covered shape memory polymeric fiber according to the current invention, the vinyl acetate content in the poly[ethylene-co-vinyl acetate] (PEVA) is between 5% and 50% of the total weight of the polymer. In a preferred embodiment of the invention, the vinyl acetate content in poly[ethylene-co-vinyl acetate] is between 3 wt% and 45 wt% of the total weight, alternatively preferably may have a degree of crystallinity in the numerical range obtained by combining any two of the following end point values: 3%, 5%, 7%, 9%, 11%, 13%, 15%, 17%, 19%, 21%, 23%, 25%, 27%, 29%, 31%, 33%, 35%, 37%, 39%, 41%, 43%, or 45%. This is because the VA content significantly influences the properties of the PEVA, such as its flexibility, thermal behavior, and shape memory characteristics. An increase in VA content is associated with a decrease in degree of crystallinity.

[0116] The vinyl acetate content (VA-content) of cPEVA and PEVA in the context of this invention can be preferably determined with derivative thermogravimetric (DTG) analysis. Two decomposition stages of cPEVA and PEVA can be observed, which are associated with the formation of volatile products. The first peak of the DTG curves occurs in the temperature range from 300 °C to 410 °C, which can be attributed to the deacetylation of VA segments, while at higher temperatures around 420 °C to 510 °C the second peak for the decomposition of the residues occurs, which is caused by the breaking of the C-C bond along the main chains. Thus, the composition of cPEVA could be determined based on the weight loss of the acetic acid groups, according to:

$$VA - content \text{ wt}\% = \frac{w_1 \times \left(\frac{M_w^{VA}}{M_w^{acetate}} \right)}{w} \times 100\%,$$

wherein w_1 is the weight loss due to the deacetylation of the VA segments in the temperature range from 300 °C to 410 °C and w is the total weight of the PEVA and cPEVA samples. M_w is the molar mass of vinyl acetate (VA) and acetic acid (acetate) groups.

[0117] In a preferred embodiment of the covered shape memory polymeric fiber according to the invention, the poly[ethylene-co-vinyl acetate] (PEVA) comprises a cross-linker and/or an initiator. Comprising in this context is preferably realized by blending one, preferably at least two, poly[ethylene-co-vinyl acetate] polymer(s) with different vinyl acetate contents, with a cross-linker, preferably TAIC and an initiator, preferably BP, before the cross-linking initiated with irradiation (curing), yielding cPEVA, preferably covalently cross-linked cPEVA.

[0118] Additionally, the crystallinity index (χ_c) of the PE segments in PEVA and cPEVA shape memory polymers can be calculated from the exothermic curves obtained during the DSC analysis. The crystallinity index

is a crucial parameter indicating the degree of crystallinity within the polymer structure, which impacts the material's mechanical and thermal properties. The calculation is based on the following Equation:

$$\chi_c = \frac{\Delta H_m}{\Delta H_{100}}$$

[0119] Here, ΔH_m represents the integrated melting enthalpy, corresponding to the area under the melting peak in the DSC curve. ΔH_{100} is the specific melting enthalpy for a 100% crystalline PE segment, which in this example is 287.3 J/g. This calculation allows for determination of the crystalline structure within PEVA and cPEVA shape memory polymers. This DSC method provides a comprehensive thermal analysis, ensuring that the shape memory polymers used in the invention meet the required specifications for optimal performance in covered shape memory polymeric fiber (cSMPF) of the invention and/or shape memory textile and/or shape memory fabric comprising the same. Experimental results from some exemplary covalently cross-linked poly[ethylene-co-vinyl acetate] (cPEVA) and poly[ethylene-co-vinyl acetate] (PEVA) with different vinyl acetate contents are shown in table 1.

[0120] In some preferred embodiments of the covered shape memory polymeric fiber according to the current invention, the amount of cross-linking agent and initiator in the poly[ethylene-co-vinyl acetate] polymer ranges from 0.5% to 5.0% by weight.

[0121] In some other preferred embodiments of the covered shape memory polymeric fiber according to the current invention the cross-linker is triallyl isocyanurate (TAIC).

[0122] In some further preferred embodiments of the covered shape memory polymeric fiber according to the current invention, the amount of cross-linking agent and initiator in the poly[ethylene-co-vinyl acetate] polymer ranges from 1.0% to 2.0% by weight.

[0123] In a preferred embodiment of the covered shape memory polymeric fiber according to the invention, the cross-linking agent is benzophenone (BP).

[0124] In an embodiment of the invention, the polymers are optionally present as a blend, wherein the content of each polymer in the blend is at least 10 wt%.

[0125] In some preferred embodiments, the content of each shape memory polymer in the blend may be in the numerical range obtained by combining any two of the following end point values: 1 wt%, 3 wt%, 5 wt%, 7 wt%, 9 wt%, 11 wt%, 13 wt%, 15 wt%, 17 wt%, 19 wt%, 21 wt%, 23 wt%, 25 wt%, 27 wt%, 29 wt%, 31 wt%, 33 wt%, 35 wt%, 37 wt%, 39 wt%, 41 wt%, 43 wt%, 45 wt%, 47 wt%, 49 wt%, 51 wt%, 53 wt%, 55 wt%, 57 wt%, 59 wt%, 61 wt%, 63 wt%, 65 wt%, 67 wt%, 69 wt%, 71 wt%, 73 wt%, 75 wt%, 77 wt%, 79 wt%, 81 wt%, 83 wt%, 85 wt%, 87 wt%, 89 wt%, 91 wt%, 93 wt%, 95 wt%, 97 wt%, or 99 wt%, wherein the content of all polymer contents in the blend add up to 100 wt%.

[0126] In this disclosure, the terms "cross-linker", "crosslinker", and "cross-linking agent" are synonymous and describe chemical compounds employed to establish cross-links within a polymer matrix. These agents are characterized by having at least two reactive functional groups, essential for forming cross-links, such as covalent bonds, between separate polymer chains and/or between different segments of the same polymer chain. In an alternative mechanism, certain cross-linkers act by creating reactive sites directly on the polymer chains. These sites subsequently react with each other, facilitating cross-linking. This type of cross-linking typically involves the use of strong acids or peroxides.

[0127] The proportion of the cross-linker relative to the total weight of the polymer is a critical factor, as it significantly influences the degree of cross-linking. It is preferable that the proportion of the cross-linker, relative to the total weight of the shape memory polymer or its precursor prior to the initiation of the cross-linking process, falls within the range of 0.05 wt% to 5 wt%. More specifically, an optimal range for enhanced efficacy and balance in the properties of the resulting polymer is between 0.1 wt% and 2.5 wt%. This proportion is critical in influencing the final properties of the shape memory polymer, particularly in terms of its cross-linking density, mechanical strength, and thermal responsiveness.

[0128] In the context of shape memory polymers the degree of cross-linking holds particular significance. A higher degree of cross-linking typically correlates with reduced crystallinity, in particular reduced degree of crystallinity, within the polymer. The degree of crystallinity directly affects the transition temperatures of these semi-crystalline polymers, which is important in tailoring their thermal-responsive behavior to meet the specific requirements of the current invention. Therefore, the selection and concentration of cross-linkers must be carefully considered to achieve the desired balance between degree of cross-linking and crystallinity, ensuring the optimal performance of the shape memory polymers in their intended applications.

[0129] In the context of ethylene-co-monomer-polymers or di- or multi-block-co-polymers comprising at least one polyethylene and/or polyalkene polymer block, cross-linkers are preferably substances with at least two, more preferably between 2 and 4 alkene functional groups, preferably allyl or vinyl groups. These cross-linkers can react with radicals generated on a polymer, preferably a shape memory polymer within the meaning of the present invention, by irradiation and/or an initiator, preferably a photoinitiator, such as benzophenone (BP). This has the advantage that no functional groups are required for this cross-linking, although some functional groups can be cross-linked radically, such as acetate groups, and that the degree of cross-linking can be influenced by the irradiation time and/or the dose and/or the concentration of the initiator

and/or the cross-linker, resulting in a variety of different parameters suitable for a wide range of potential shape memory polymer.

[0130] The gel content in a polymer and its degree of cross-linking are closely related concepts in polymer chemistry. In a specific embodiment of the present invention, a shape memory polymer, which is preferably a cross-linked shape memory polymer and most preferably a covalently cross-linked shape memory polymer, is characterized by a gel content ranging from 60% to 100%, with a more preferred range being between 70% and 100%. This embodiment is particularly significant for ensuring the desired physical and mechanical properties of the shape memory polymers used in various applications. In some preferred embodiments, the gel content a shape memory polymer may be in the numerical range obtained by combining any two of the following end point values: 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99%, and 100%.

[0131] The polymers constituting the 2W-SMPFs, or their blends, in this embodiment, can undergo cross-linking through different mechanisms, including covalent bonds, ionic interactions, or crystallite formation. However, the emphasis in this embodiment is on covalently cross-linked polymer networks, which are known for their robustness and stability. According to standards such as ASTM D2765 or ISO 10147, these covalently cross-linked polymers exhibit a gel content ranging from 60% to 100%.

[0132] To determine the gel content (G) of the cross-linked 2W-SMPFs, specifically the cross-linked shape memory polymers within these fibers, a solvent extraction method is employed. This involves immersing the polymer sample in solvents like toluene or xylene at a constant temperature of 110°C or lower. The extraction process lasts for 24 hours, followed by an additional 24 hours of solvent evaporation in a vacuum oven set at 45°C. The gel content is then calculated using the following equation:

$$G = \frac{m_d}{m_{iso}} * 100\%$$

[0133] Here, m_d represents the dry weight of the sample after extraction, and m_{iso} is the isolated weight of the sample before extraction.

[0134] It's important to note that for the purposes of this embodiment, the fibers that are not subjected to extraction are used for covering and for conducting various investigations, such as thermo-mechanical analysis and evaluation of shape memory properties.

[0135] In some preferred embodiments, the two-way shape memory polymeric fiber (2W-SMPF), which is comprised by a 2W-cSMPF and the 2W-SMT of the current invention, comprises an electrically conductive material, preferably electrically conductive nanoparticles (ENPs), electrically conductive particles, electrically conductive coating(s), or electrically conductive

core-shell systems. This enables an external stimulus ($E_0/E_1/E_2$) in the form of an electrical current to switch the 2W-cSMPF between two states, preferably S_1 and S_2 . This can be caused by resistive heating of the fiber, leading to internal thermal activation of the fibers.

[0136] In some preferred embodiments, the two-way shape memory polymeric fiber (2W-SMPF), which is comprised by a 2W-cSMPF and the 2W-SMT of the current invention comprises magnetically active fillers. This allows an external stimulus ($E_0/E_1/E_2$) in the form of an alternating magnetic field to switch the 2W-cSMPF between two states, preferably S_1 and S_2 . This can be caused by electromagnetic heating of the fiber, leading to internal thermal activation of the fibers.

[0137] Furthermore, in some preferred embodiments, the 2W-SMPF comprised by the 2W-cSMPF is configured as a composite fiber material. A composite fiber material in this context is understood as a fiber or a bundle of fibers, wherein fillers, also referred to as active fillers, configured as particles or nanoparticles, in particular electrically conductive and/or magnetically active fillers, are integrated as part of the shape-memory polymer matrix and/or are mixed in during an extrusion step, such as a cross-linking agent and/or initiator as disclosed herein. Another embodiment of a 2W-SMPF configured as a composite fiber material is a core-shell fiber configured as a core-shell assembly, wherein the 2W-SMPF is either core or shell and an electrically conductive and/or magnetically active coating or composite forms the corresponding shell or core, respectively.

[0138] "Electrically conductive active fillers", in particular configured as particles or nanoparticles, are electrically conductive materials, such as metal or carbon based, and preferably chosen from the list consisting of carbon black (CB), graphene (G), graphene oxide (GO), reduced graphene oxide (rGO), carbon nanotubes (CNTs), gold (Au) nanoparticles, silver (Ag) nanoparticles or copper (Cu) nanoparticles or a combination thereof. These active fillers may be combined with the SMP(s) as disclosed herein and allow for programming with an electrical external stimulus ($E_0/E_1/E_2$). These fillers may be incorporated into the 2W-SMPF via dip coating, compounding, for example by extrusion, as a core-shell system, which leads to a composite fiber material. This selection allows for a wide range of customized mechanical and electrical properties.

[0139] An 2W-SMPF comprising an electrically conductive material has preferably at a conductivity σ in the range of $2.5 \cdot 10^5 \text{ S m}^{-1}$, preferably between $5.0 \cdot 10^4 \text{ S m}^{-1}$, as determined by a four-terminal sensing measurement method. In some preferred embodiments of the 2W-cSMPF configured as a composite material with electrically conductive particles or nanoparticles, the conductivity is in the range of 2.5 to 1000 S m^{-1} . In some preferred embodiments of the 2W-cSMPF configured as a coated or core core-shell system, the conductivity is in the range of 200 to 10^5 S m^{-1} .

[0140] In some preferred embodiments, electrically conductive nanoparticles (ENPs) have a size in the range of 1 to 500 nm , preferably between 10 and 100 nm . Preferably, an electrically conductive or magnetic particle has a size between 1 nm and 500 nm , preferably between 10 nm and 100 nm .

[0141] In embodiments related to 2W-SMPF with an electrically conductive coating or configured as electrically conductive core-shell systems, the active fillers, in particular the magnetically active fillers and/or the electrically conductive active fillers are provided in form of an ink or composite core, and 2W-SMPF can be either coated with these inks or arranged around a composite core. Preferably, an ink or n composite core in the spirit of this invention consists of an active filler, preferably between 50 to $95 \text{ wt\%}$, and a polymer, between $50 \text{ wt\%}$ and $5 \text{ wt\%}$, wherein the polymer and active filler add up to 100% , as preferably determined gravimetrically.

[0142] "Magnetically active fillers", are ferromagnetic or ferrimagnetic particles incorporated into the structure or grafted to the surface of a 2W-SMPF of the current invention, and are in particular configured as particles or nanoparticles, are chosen from the list consisting of iron, nickel and cobalt, combinations thereof and their oxides, preferably iron oxides selected from ferrite, magnetite (Fe_3O_4) or maghemite (Fe_2O_3). These active fillers may be combined with the SMP(s) as disclosed herein allow for programming with a magnetic external stimulus ($E_0/E_1/E_2$). Magnetic nanoparticles (MNPs) range in size from 1 to 500 nm , preferably between 10 and 100 nm . Magnetic nanoparticles can agglomerate into or configured as nanoclusters, which comprise a number of nanoparticles, e.g. 10 to 300 nanoparticles, that exceed the size limit and are associated with sizes in the range of 100 to 500 nm . In addition, nanoparticles and their nanoclusters can be provided in the form of nanochains. These configurations, in particular the control of the size of the magnetically active fillers that can lead to superparamagnetism, for example below 128 nm for ferrite nanoparticles, and their delivery, allow the magnetic properties of the 2W-SMPF containing these nanoparticles to be adjusted, as well as their content and distribution.

[0143] Preferably, the surface of magnetically active fillers, especially nanoparticles, is often modified by surfactants, silica, silicones or phosphoric acid derivatives to increase their stability in solution, or coated with a protective layer, such as an oxide layer of a SiO_2 coating, such as iron oxide nanoparticles or nanoclusters with a SiO_2 coating.

[0144] In some preferred embodiments, the weight fraction (wt%) of the fillers, in particular magnetically and/or electronically active fillers, in the composite is in a range of $2.5 \text{ wt\%}$ to $50 \text{ wt\%}$, preferably $5 \text{ wt\%}$ to $45 \text{ wt\%}$, as preferably determined gravimetrically.

[0145] In some preferred embodiments, the covering element comprises an electrically conductive and/or electromagnetically heatable material, which is prefer-

ably configured as a composite fiber material as disclosed herein.

[0146] In some alternative preferred embodiments, the covering element is an electrically conductive element comprising metal filaments or wire mesh. With staple fibers, it is possible to spin short strands of regular yarns with metal yarns. Electrically conductive yarns can consist of a central metal strand around which a regular yarn is woven. Another preferred embodiment is a metallized yarn, in which a base fiber or material is directly coated with a conductive metal such as silver or gold. These embodiments allow the modification of common materials for the covering element to enable electric conductivity.

[0147] In some preferred embodiments, the covering element comprises or consists of a conductive polymer. Conductive polymers (CP) are a class of organic, electronically conjugated polymer materials that are loosely fixed to a backbone and exhibit electro-optical properties similar to those of metals. Because pi electrons can move freely, they can form electrical paths for mobile charge carriers. Preferred conductive polymers include polypyrrole (PPy), polyaniline (PANI), polythiophene (PT), and poly(3,4-ethylenedioxythiophene) (PEDOT), and any of these conductive polymers doped with polystyrene sulfonate (PSS), for example. These materials are particularly suitable for a covering element in the sense of the present invention.

[0148] The current invention furthermore is related to a method for producing a 2W-SMT as well as the 2W-cSMPF comprised by it. The general process for manufacturing disclosed herein relates to the general steps of producing (P) a polymeric fiber, in particular through an extrusion process, then winding a covering yarn around the core fiber, the resulting covered fiber is integrated with a base fiber and/or base fabric to yield a textile. At different points during the manufacturing process, a shape memory step (SM), which provides the shape memory properties to the material by a specific transformation step, such as cross-linking, is performed, in particular by a post processing step, which can be included or combined with one of the aforementioned general steps. A number of post processing steps, in particular cross-linking steps, preferably by UV, beta, or gamma radiation, thermal treatment, coating or compounding steps or textile post processing steps are preferably included in the method.

[0149] In particular, the current invention pertains to a method for producing a two-way shape memory textile (2W-SMT) (1), comprising the steps of

a) providing a 2W-SMPF by a sequence of a fiber production process (P) from base materials (BM), preferably by extruding or spinning, a fiber covering step (CV), wherein a covering element is wound around the produced fibers at a rate of 300 to 6000 twists per meter, yielding produced covered fibers, preferably 2W-cSMPF(s),

b) providing a base fiber and/or a base fabric, preferably adapting the base fiber or base fabric to a predetermined surface contour; and

5 c) integrating or intertwining the produced covered fibers, preferably 2W-cSMPF(s), into the base fabric and/or base fiber to form a designated shape memory area,

10 wherein at least one post-processing step (PF, PC, TP) introducing 2W-SM properties is provided in or after one of steps a) or c) wherein a post-processing step preferably comprises cross-linking, coating, compounding or heat treatment, which correspondingly yields a 2W-SMPF, 2W-cSMPF or 2W-SMT.

[0150] In a further embodiment, the method for producing a two-way shape memory textile (2W-SMT) (1) also comprises the step of programming a programmed state (S_1/S_2) of the 2W-SMPF by applying an external stimulus (E_0) under a predetermined set of conditions, preferably in conjunction with a step a) or c). This allows the integration of the programming of the 2W-SMT or the comprised 2W-SMPF(s) and 2W-cSMPF(s) from the base state (S_0) directly in the manufacturing process, which allows for more precise adjusting of the material properties of the 2W-SMT.

[0151] Alternatively cross-linking as shape memory property providing step can be performed in-line with extrusion, where the fibers are directly cross-linked after extrusion and before winding step, for example by an reactive extrusion by adding a reactive cross-linking agent during the extrusion and/or subjecting the fibers to irradiation, while stretching of the polymer fibers with after extrusion can be performed up to 10 times comparing to unstretched extruded fiber. This is preferably done by pulling the fibers through a cooling bath and winding them around a bobbin with a defined tension or force. This embodiment represents a shape memory step which is combined with the fiber production process, an allows for a streamlined production line.

[0152] "Cross-linking" herein typically refers to a covalent cross-linking reaction in a polymeric fiber, typically introduction 2W-SM properties. For polymers containing ethylene or olefin monomers, as in this case, the curing can involve direct radical cross-linking. This is often achieved using peroxides and/or photoinitiators, such as benzophenone, as initiators, and preferably a cross-linking agent, such as TAIC. The initiators decompose under specific conditions, such as thermic activation or irradiation with electromagnetic radiation, to generate free radicals, which facilitate the formation of covalent bonds between polymer chains. It is preferably carried out using irradiation methods, such as UV, beta, or gamma radiation in combination with an initiator, and optionally a cross-linking agent. These methods involve exposing the extruded polymer to high-energy radiation, which generates free radicals and initiates the cross-linking process. Irradiation provides a

controlled way to achieve cross-linking, allowing for precise manipulation of the polymer's properties.

[0153] Alternatively, the cross-linking step might be applied as a post processing step after fiber production process from the base materials (BM), preferably by an extrusion process with solution spinning or melt spinning, after the fiber covering process, or after the textile manufacturing process, in contrast to the cross-linking during fiber production, which may be referred to as "in-line" process.

[0154] In a preferred embodiment of the invention, the base materials before the fiber production process are provided through a compounding process. This process involves several controlled steps to ensure the optimal blending of the polymer(s) precursors and further components, preferably initiator and cross-linking agent.

[0155] In some preferred embodiments of the invention related to a 2W-SMPF comprised by the 2W-cSMPF which is configured as a composite fiber material, the fillers, preferably configured as particles or nanoparticles, in particular electrically conductive and/or magnetically active fillers, are provided as base materials or include into the mixture in a later extrusion step. This allows the provision of composite fiber material in a single fiber production process.

[0156] Following the first extrusion, the continuous filament may be cut into granulate. This palletizing step transforms the extruded blend into manageable granules, facilitating further processing and handling. Furthermore, this blend may be advantageously stored under controlled conditions for further processing.

[0157] In some preferred embodiments, the shape memory polymer precursor may be pelletized and extruded multiple times to achieve a more uniform distribution.

[0158] In a preferred embodiment, the shape memory polymeric fibers before curing are provided as monofilaments with diameters ranging from 0.05 mm to 0.5 mm. This diameter range is chosen to provide a balance between the mechanical strength of the fibers and their flexibility. Preferably, the mixture is fed into a single screw extruder for extrusion. The extruder is equipped with filament dies of various diameters to produce monofilaments with the desired thickness as disclosed herein.

[0159] In some embodiments of the extrusion process, the feeding zone may be maintained at room temperature, preferably between 10 and 30 °C, to prevent premature melting of the mixture. The temperature may then increase to 80°C, followed by a consistent temperature between 80 and 150°C, preferably 100 to 120 °C across the melting zones. Finally, the temperature at the die is set to between 60 and 120°C, preferably 90 to 110°C. The screw rotation speed during extrusion is kept between 5 and 20 rpm. This ensures that the monofilaments are extruded at a consistent rate and with uniform diameter.

[0160] In some preferred embodiments, the screw rotation speed is preferably between 30-60 rpm, more preferably between 45 and 55 rpm during extrusion. This controlled environment ensures thorough mixing and melting of the components, leading to a homogeneous blend.

[0161] In another preferred embodiment of the fiber production process, the polymer fibers are provided as multifilament with a linear density of 40 to 500 dtex. This may be achieved through melt-spinning equipped with a spinneret. The spinneret contains multiple holes, preferably between 20 to 200, more preferably between 36 to 150 through which multiple filaments are extruded. Preferably, the filaments are extruded simultaneously and collected as one continuous filament. This process allows for the production of a bundle of filaments, which can then be used in various textile applications.

[0162] The two-way shape memory polymer fibers (2W-SMPF) may be obtained by reactive cross-linking as shape memory property providing step.

[0163] In some preferred embodiments, the shape-memory step is accomplished by reactive cross-linking, which may be incorporated at different stages of the 2W-cSMPF production process. In this embodiment, the polymer fibers are provided with a reactive cross-linking system, for example a thermally or chemically activatable initiator, preferably an organic peroxide, such as dicumyl peroxide or benzoyl peroxide, and a cross-linking agent, such as triallyl isocyanurate (TAIC), or a cross-linking system such as a thiol-ene cross-linking system. The cross-linking reaction is triggered under controlled temperature and dwell-time conditions either in-line directly after extrusion, preferably a reactive extrusion process, or off-line as a post-processing step.

[0164] In some particular preferred embodiments, the two-way shape memory polymer fibers (2W-SMPF) are created by a shape memory property providing step by reactive cross-linking under irradiation, which may be integrated into different steps of the 2W-cSMPF production process. Preferably, irradiation is carried out as a post-processing step, such as after extrusion, or after covering of the 2W-SMPFs, or as a textile post processing step after intertwining the 2W-cSMPFs into a base fabric. Preferably, irradiation is provided as UV-, beta-, or gamma-irradiation.

[0165] In some preferred embodiments, a post-processing step after the fiber production process may further include a coating and/or compounding step. A coating ink is prepared by dissolving a polymer in a suitable solvent at a suitable temperature. After cooling, the active filler is added to this solution and the solution is stirred overnight. The coating solution can be applied to the fibers, preferably 2W-SMPF(s) by dip coating, wherein the fibers can be dipped several times to achieve the required coating thickness.

[0166] In another preferred embodiment, the compo-

site fiber material is provided by a multilayer fiber extrusion, in which the conductive ink can be core or sheath and is extruded together with the SMP fiber, also known as a coextrusion process.

[0167] Beta-radiation can advantageously be carried out with different doses, preferably between 50 and 800 kGy, particularly preferably between 90 and 600 kGy, whereby different degrees of cross-linking can be achieved depending on the specific requirements of the application. This type of irradiation is particularly effective in achieving a high degree of cross-linking by inducing free radicals in the polymer.

[0168] In addition, the process for providing a 2W cSMPF also offers a fiber covering process that can be performed before or after a post-processing step such as cross-linking. The 2W-cSMPF fiber or fiber bundle is fed at a constant speed to a suitable sheathing machine or covering machine. The covering is applied either with two sheathing elements, preferably covering yarns, that are wound around the cSMPF core fiber opposite each other, or in two successive covering processes. After the covering process, the 2W-cSMPF has an elongation of at least 100% to 800%, preferably 200% to 500%.

[0169] In an embodiment of the textile manufacturing process, the provided fibers, preferably 2W-cSMPF(s), are integrated or intertwined by a winding process, whereby they are wound crosswise onto conical or cylindrical bobbins as a template for the knitting machine. In this process, it is particularly important that the fibers are stretched as little as possible and that the templates are wound cleanly, especially at the turning points, to avoid loops. This is ensured by a constant take-off angle.

[0170] In an embodiment of the textile manufacturing process, the provided covered fibers, preferably 2W-cSMPF(s), are integrated or intertwined by a knitting process, wherein the provided covered fibers, preferably 2W-cSMPF(s), are supplied to a knitting machine. During the knitting process, the provided fibers are fed at a controlled and constant force to ensure a uniform supply of the covered fibers.

[0171] Certain terms and derivations thereof are used in the following description for convenience only and are not intended to be limiting. For example, words such as "up", "above", "upward", "down", "below", "downward", "left" and "right" refer to directions in the drawings to which reference is made, unless otherwise indicated. Similarly, words such as "inward" and "outward" refer to directions directed toward or away from the geometric center of a device or area or specific parts thereof. References in the singular include the plural and vice versa, unless otherwise indicated. "

[0172] In the context of this patent application, Differential Scanning Calorimetry (DSC) is defined as an analytical technique used to measure the thermal properties of SMPs, especially semi-crystalline SMPs. DSC is instrumental in determining the thermal transitions of

these materials, such as melting temperature, glass transition temperature, and crystallization behavior.

[0173] In the context of this patent application, the term "subject" refers to individuals or groups who may benefit from the use of covered shape memory polymeric fiber (cSMPF) and/or a shape memory textile and/or shape memory fabrics comprising the same as disclosed herein.

[0174] A "non-shape memory fabric" or a "non-shape memory fiber" is any fabric or fiber structure that doesn't comprise or consist of a two-way and/or one-way covered or uncovered shape memory polymeric fiber (cSMPF/SMPF) according to the invention. Common fabrics and/or fibers comprised by the fabrics are known to the person skilled in the art.

[0175] Finally, it should be noted that all features mentioned in the application documents and in particular in the dependent claims, despite the formal reference made to one or more specific claims, should also be granted independent protection individually or in any combination.

[0176] Further advantages, features and possible applications of the present invention are also apparent from the following description of embodiments and the drawings. All the features described and/or illustrated form the object of the present invention, either individually or in any combination, even independently of their summary in the claims or their references.

[0177] The features mentioned in the claims and in the description can each be essential to the invention individually or in any combination.

[0178] In addition, it should be noted that the skilled person will undoubtedly recognize that the individual features described in the specific embodiments above can be combined with each other in an appropriate manner, provided that there is no contradiction, whereby a separate description of various possible combinations is dispensed with in order to avoid unnecessary repetition.

EXAMPLES

[0179] The present invention is explained in more detail with reference to the following figures and embodiments, without limiting the invention to these. In particular, features shown in the individual figures and described for the respective example are not limited to the respective individual example.

[0180] Examples of embodiments are shown to explain the basic principle of the device according to the invention. It should be noted that the ratio, the dimensions, the extent of deformation or the amount of displacement of the components according to the invention do not correspond to reality for the sake of illustration.

[0181] The singular includes the plural, unless the context clearly indicates otherwise.

[0182] The features, characteristics and advantages

of the present invention described above and the manner in which they are achieved will be more clearly understood in the context of the following description of the embodiments. Where the term "may" is used in this application, it refers to both the technical possibility and the actual technical implementation.

[0183] In the following, the invention will be described in detail by referring to exemplary embodiments that are accompanied by figures, in which:

Fig. 1 shows an embodiment of two-way shape memory textile 2W-SMT (1).

Fig. 2 Shows a further embodiment of two-way shape memory textile 2W-SMT (1).

Fig. 3 illustrates an embodiment of a covered shape memory polymeric fiber (2W-cSMPF) (3.0).

Fig. 4 illustrates three embodiments (**4A - 4C**) of a base fiber (1.1) as well as a base fiber (1.1) with integrated or intertwined 2W-cSMPF (3.0).

Fig. 5 illustrates exemplary embodiments of four two-way shape memory textiles (2W-SMT) (1) arranged on a surface contour (2.0).

Fig. 6 illustrates the processes for manufacturing a 2W-SMT (1) in the spirit of the current invention.

Design examples

[0184] With reference to the following figures and examples of embodiments, the present invention will be explained in more detail without limiting the invention thereto.

[0185] **Figure 1** illustrates an exemplary embodiment of programming procedure for 2W-SM of a 2W-SMT (1) having a shape memory region (1.3). In this exemplary embodiment of a cylindrical two-way shape memory textile (2W-SMT) (1) having a shape memory region (1.3), arranged in the middle of the textile around the whole circumference of the cylindrical form of the 2W-SMT (1), but could only be included into parts of the textile. The 2W-SMT is here fitted around an object of cylindrical shape having a surface contour (2.0). The base state (S_0) of the 2W-SMT (1) is typically characterized with the smallest dimensions. i.e. circumference and, therefore, radius of the cylinder. The 2W-SMT in its base state S_0 is here subjected to an external stimulus E_0 , in this exemplary embodiment sequential heating to programming temperature T_{prog} and force F , which leads to a stretching to the desired and defined deformation $\varepsilon_{\text{prog}}$. Here, linear deformation of shape-memory yarns in the structure of 2W-SMT unambiguously corresponds to deformation of the 2W-SMT (cir-

cumference and cylinder diameter) with precision sufficient for predictable and controllable 2W-SM realization. Then, in this embodiment, when after E_0 was applied and removed, 2W-SMT reaches state S_1 . This is the state which is adapted around the surface contour (2.0) of the object, allowing the 2W-SMT to fit around the cylindrical object, providing a compression pressure (5.0) at the surface contour (2.0) in the shape memory region (1.3). After subjecting it to a further external stimulus (E_1), the 2W-SMT (1) transforms from the programmed state S_1 to the programmed state S_2 , caused by the expanding of the included two-way covered shape memory polymeric fibers (2W-cSMPF) integrated into the base fabric (1.1). When the further external stimulus is reversed or no longer applied ($-E_1$), for example by removal of the further external stimulus (E_1) source, or the passing of a time interval, or a second stimulus is applied (E_2), such as cooling, the 2W-cSMPF and the 2W-SMT comprising it contracts to the programmed state S_1 .

[0186] **Figure 2** depicts the 2W-SMT (1) of figure 1, wherein the programming from the base state (S_0) with the external stimulus E_0 , in this exemplary embodiment sequential heating to programming temperature T_{prog} and force F , which leads to a stretching to the desired and defined deformation $\varepsilon_{\text{prog}}$, leads to an expanded 2W-SMT (1) in the second programmed state (S_2) which has a greater circumference than the object with a cylindrical surface contour (2.0). Through application of a reversible further external stimulus (E_1), the 2W-SMT (1) is changed to the first programmed state (S_1), which contracts the 2W-SMT (1) in the shape memory area (1.3) and provides a defined compression pressure (5.0). The application of a complementary reversed ($-E_1$) or additional further external stimulus (E_2) restores the programmed state (S_2), which enables a reversible cycle.

[0187] **Figure 3A** and **3B** illustrate exemplary embodiments of two deformation states of a two-way covered shape memory polymeric fiber (2W-cSMPF) (3.0) according to the current invention. In both states the 2W-cSMPF (3.0) has a 2W-SMPF (3.1) as a core fiber and a covering element (3.2) wound around the 2W-SMPF (3.1). In **Figure 3A** the 2W-SMPF (3.0) is in an unstretched (undeformed) state with a length L_0 (4.0) and a diameter D_0 (4.1). **Figure 3B** shows the 2W-SMPF (3.1) in a stretched state with a length L_1 (4.3) and a diameter D_1 (4.4). The change in coils/twists spacing (4.2/4.5) of the covering element (3.2) upon mechanical deformation of the 2W-SMPF during programming under an external stimulus (E_2) (from **Figure 3A** to **Figure 3B**) and recovery (from **Figure 3B** to **Figure 3A**) in absence of the external stimulus can be seen. Stretching (elongation) of the 2W-SMPF (3.1) having the covering element (3.2) wound around it causes the pitch (4.2, 4.5), i.e. the distance between two loops of the twist, of the covering element (3.2) around the 2W-SMPF to increase from r_0 to r_1 , whereby the density of

entwining (p_1) decreases.

[0188] Figure 4 shows three exemplary embodiments (4A-4C) of a base fabric (1.1) and a base fabric (1.1) with integrated or interwoven 2W-cSMPF (3.0). Figure 4A shows a section of an exemplary simple base fabric (1.1) consisting of a base fiber (1.2), in this case cotton, which is connected in a plain weave. Fig 4B shows a base fabric (1.1) of a shape memory area (1.3), which comprises base fibers (1.2), herein as black and white fibers, in plain weave, with integrated 2W-cSMPF (3.0), dashed fibers. Figure 4C shows a further integration of 2W-cSMPF (3.0) into a base fabric (1.1) made of base fibers (1.1), here as a weft-knitted fabric.

[0189] Figure 5 shows some exemplary application sites of 2W-SMT (1), which are configured as compression garments (6.0) and are applied to the surface contour (2.0) of a body, in this case a human body.

[0190] Figure 6 shows an overview of the possible production processes of a 2W-SMPF, 2W-cSMPF and 2W-SMT, as disclosed herein. There are 6 different production layers (PL1 to PL6) shown, representing a range of steps that can be implemented in a single process step or as iterative steps in sequential order or just as possible steps. Depending on the use of the 2W-SMT, the programming can be implemented from the base state (S_0), depicted in the middle row, in combination with or after a step in the corresponding production layer (PL1 to PL6). The lefthand row shows the polymer fibers (PF1/PF2), covered polymer fibers (cPF1/cPF2) and covered polymer fiber textiles before the addition of the 2W-SM effect, which can be implemented in various stages in process steps SM1 to SM4, which can be carried out as isolated steps or in conjunction with the respective manufacturing process step (P, FP1, PC1, TP1) and/or the first programming with external stimulus E_0 . The programming of 2W-SMT can therefore be done during textile production, e.g. by knitting, weaving, embroidering or other suitable processes (TM2); as can 2W-SMT post-processing by boarding, hot pressing or other processes (TP2); the implementation in shape memory yarns during extrusion, melt spinning, solution spinning or other processes used to produce them (P-SM1), as well as during stretching, irradiation, curing, coating or any other suitable post-processing (FP2; CV2; PC2; PC1-SM3); and with a specially designed process added between any processes in the 2W-SMT manufacturing chain or replacing any of those processes. Some of the steps are optional, e.g. in the production process of a 2W-SMT that includes a 2W-cSMPF, usually only one post-processing step (FP1, FP2, PC1, PC2, TP1, TP2) is required.

[0191] Example 1 is an example of the process of Figure 6, wherein the programming under the external stimulus (E_0) during the manufacture of the 2W-SMPF in the first processing step (P) directly from the base materials (BM), which may be polymer precursors or

polymer granules, such as e.g. a monomer, oligomer, or polymer solution, wherein a polymer fiber is produced by an extrusion step, such as solution or melt spinning, and then an integration step of the shape memory effect (SM1), such as UV irradiation, temperature treatment (β -radiation, γ -radiation, solid-state chemical reactions, leading to the formation of shape memory properties in the polymer fiber (PF1), which can be combined with the external stimulus (E_0), such as sequential heating to the programming temperature T_{prog} and stretching to the deformation ϵ_{prog} , resulting in 2W-SMPF-1 being in the first or second programmed state (S_1/S_2). After the fiber has been processed (FP2), a conductive coating is applied, resulting in the coated 2W-SMPF-2, which is then capped (CV2) in a process with a capping element in a single layer to obtain a 2W-cSMPF-1. This can be further post-processed (PC2), for example by applying a second layer of a covering element, to obtain 2W-cSMPF-2. This fiber is then integrated into a base fabric to form a 2W-SMT-1 in the textile manufacturing process (TM2) by knitting. Further textile post-processing, where pieces of 2W-SMT-1 are cut apart and combined by stitching (TP2) to form a compression garment, creates the finished 2W-SMT-2.

[0192] Example 2 is an embodiment of the preceding examples, herein detailing the process for a 2W-SMT (1) comprising a 2W-cSMPF (3.0) itself comprising an electrically conductive material.

[0193] The base materials (BM) were as following: Poly[ethylene-co-(vinyl acetate)] (PEVA) with a vinyl acetate content of 28 wt% (Elvax 260A, DuPont, triallyl isocyanurate (TAIC) (99%, Sigma-Aldrich, Steinheim, Germany), toluene (99.8% SigmaAldrich, Steinheim, Germany), carbon black (CB) (Super P conductive, 99+%, Alfa Aesar,

[0194] ThermoFisher GmbH, Kandel, Germany), graphene nanoplatelets (Sigma-Aldrich, Steinheim, Germany) and carbon nanotubes (CNTs) (Sigma-Aldrich, Steinheim, Germany) were used as received.

[0195] In the first processing step (P) of this example of the process as shown in Figure 6, the base materials (BM) PEVA granulates 99 wt% and TAIC 1 wt% were manually mixed at first and afterward compounded in a twin-screw extruder (Euro Prism Lab, Thermo Fisher Scientific, Waltham, USA) with a temperature profile of 25, 80, 110, 110, 110, 110, and 100 °C (from feed to die) and at a screw-speed of 50 rpm. Then the blend granulates (PEVA+TAIC) were again extruded through a filament die to obtain fibers with a thickness of 0.4 ± 0.1 mm in a single screw extruder (Extrudex, Mühlacker, Germany) with an identical speed and temperature profile as used in compounding. These fibers were subsequently cross-linked by a gamma beam of 165 kGy, which introduces shape memory effect (SM1), yielding 2W-SMPF-1. Non-cross-linked PEVA fibers were prepared by directly extruding PEVA in a single screw extruder (Extrudex, Mühlacker, Germany) (FP1).

[0196] Example 3 is an embodiment of the preceding

examples, wherein a conductive fiber coating was prepared and applied to the 2W-cSMPF-1 of example 2. The coating is prepared by dissolving 1 g of PEVA in 60 mL of toluene at 90 °C for 3 h. After cooling, 1, 2, 3, or 4 g of carbon black (CB) filler particles with a particle size between 20 and 80 nm were added with additional 40 mL of toluene and the solution was kept stirring for overnight. This coating solution was applied to the cross-linked fibers (2W-SMPF-1) via dip coating, where fibers were dipped four consecutive times in coating solution for 5 s, as a fiber post processing step (FP2). The fibers are then wrapped in a covering step (PC2) with a polyamide covering element, with the 2W-SMPF being fed to the covering machine at a constant speed. It is covered with two covering elements, here as a polyamide covering yarn, which are wound around the cSMPF core fiber at a rate of 2000 turns per meter, lying opposite each other. The resulting 2W-cSMPF-1 is used without further processing in a textile manufacturing step (TM2) and thermally programmed under E_0 in this state.

[0197] Example 4 is an embodiment of the preceding examples, wherein the 2W-cSMPF-1 of example 6 is provided as a core-shell composite fiber with a composite core. Conductive fillers, herein graphene, were first mixed with PEVA and 5 wt% ethanol with a content of 25 wt% graphene. After evaporation of ethanol, the mixture was compounded in a twin-screw extruder (Euro Prism Lab, Thermo Fisher Scientific, Waltham, USA) with a temperature profile of 35, 80, 110, 115, 120, 100, and 80 °C (from feed to die) and a speed of 50 rpm. Afterward blend PEVA electrically conductive filler granulates were extruded to obtain fibers in a single screw extruder (Extrudex, Mühlacker, Germany) with same speed and temperature as compounding. Conductivity of fibers was analyzed by Series 2410 SourceMeter (Keithley, Cleveland, Ohio, United States) with a source voltage range between 5 μ V to 1100 V and a measure current range from 10 pA to 1.055 A. Crocodile shaped electrodes were used to connect the fibers with the source meter, whereas the surface temperature was monitored by an infrared (IR) camera (Jenoptik AG, Jena, Germany).

[0198] Example 5 is an embodiment of the preceding examples and refers to a magnetically active 2W-cSMPF comprised by a 2W-SMT. Herein, the materials were used as following: Spherical-shaped iron oxide (Fe_3O_4) nanoparticles of size 20-30 nm and alpha- Fe_2O_3 of 100-200 nm were acquired from SkySpring Nanomaterials, Inc. (Houston, TX, USA). Furthermore, particles of 30-50 nm with Fe_3O_4 core and SiO_2 shell (MagSilica50) were purchased from Fraunhofer ISC (Würzburg, Germany). Polydimethylsiloxane (PDMS) as silicon elastomer base and curing agent (SYLGARD™ 184 Silicone Elastomer Kit), (Dow chemicals, Midland, MI, USA) were used as received. Poly[ethylene-co-(vinyl acetate)] (PEVA) with a vinyl acetate content of 28 wt% (Elvax 260A, DuPont, Wilmington,

DE, USA) and triallyl isocyanurate (TAIC) (99%, Sigma-Aldrich, Steinheim, Germany) were used as delivered by the manufacturer.

[0199] The process for manufacturing the 2W-cSMPFs as composite fiber material as a core-shell material as disclosed herein, can be divided into three steps of preparation of the composite core as well as shell material and the formation of 2W-cSMPFs.

[0200] The composite core is provided in form of cPEVA fibers with a diameter of 0.4 mm and 15 cm length were relaxed in hot water (≥ 80 °C) to remove any strain from extrusion process. Then, they were deformed by stretching by 100% followed by a second deformation step by twisting. The number of twists was 30 twists per 12 cm core material length after stretching.

[0201] For the shell material, a polymer, here produced from a silicone elastomer base and curing agent were mixed in 13:1 ratio with 5 to 20 wt% iron oxide (Fe_3O_4) nanoparticles, homogenized and degassed under vacuum for half an hour to remove air bubbles.

[0202] For the production of the core-shell materials, two PTFE tubes with 1 and 2 mm diameter were used as molds. The inner molding tube with 1 mm diameter was cut through the middle from one end to the other end but leaving 5 mm, such that the two halves were still attached together. A second tube with a larger diameter served as a casing for the inner mold to avoid the flow of the solution out of the mold. The outer casing tube was cut on one side along the length for easier insertion and removal of the inner mold. The core material was then inserted into the inner molding tube. The mold was then closed on one side using Teflon tape, while the other side was left open until the insertion of the shell material mixture. Filled molds were finally inserted into a glass tube and were placed in a water bath at 50 or 60 °C overnight for curing, therefore yielding a magnetically active 2W-SMPF material, which is subsequently covered with a double layer of a covering element, herein a polyamide yarn, in a covering step.

[0203] Mechanical Properties of the composite samples were investigated on a Zwick BZ2.5/TN1S (Zwick Roell, Ulm, Germany) while experimental data were captured with testXpert II (Zwick Roell, Ulm, Germany). The tests were conducted at room temperature with a strain rate of 5 mm·min⁻¹, and elastic modulus (E) and elongation at break (ϵ_{break}) were obtained and analyzed.

[0204] Example 6 is an embodiment of example 5, in which the external stimulation of magnetically active 2W-cSMPF is tested. These 2W-cSMPFs were attached to the upper end of a copper coil (six loops, diameter 4 cm, height 4.5 cm) with a wooden rod, because the expected winding would shorten the length and pull the part hanging outside the coil into the coil, thereby exposing the entire length of the 2W-cSMPF to AMF. The samples were positioned in an AMF with a frequency of $f = 258$ kHz. The equipment consisted of a

radio-frequency generator (TIG 5/300; Hüttinger Electronic, Freiburg, Germany) and a copper coil (six loops, diameter 4 cm, height 4.5 cm). The magnetic field strength (H) could be adjusted between 7 and 30 kA·m⁻¹ by varying the output power of the generator. The samples were heated, cooled and heated again several times to ensure reproducibility. The surface temperatures for composite shell material and for 2W-cSMPFs were recorded with an infrared video camera VarioCAM® HiRes (InfraTec GmbH, Dresden, Germany) and analyzed with IRBIS 2 (InfraTec GmbH, Dresden, Germany).

REFERENCE LIST

[0205]

1	Two-way shape memory textile (2W-SMT)	
1.1	Base Fabric	
1.2	Base fiber	
1.3	Shape memory area	
2.0	Surface contour	
3.0	Two-way covered shape memory polymeric fiber (2W-cSMPF)	
3.1	Two-way shape memory polymeric fiber (2W-SMPF)	
3.2	Covering element	
4.0	Length in the unstretched state (L ₀)	
4.1	Diameter in the unstretched state (D ₀)	
4.2	Pitch of the covering element in the unstretched state (r ₀)	
4.3	Length in the stretched state (L ₁)	
4.4	Diameter in the stretched state (D ₁)	
4.5	Pitch of the covering element in the stretched state (r ₁)	
4.6	Diameter of the covering element (d)	
5.0	Compression pressure	
6.0	Compression garment	
BM	Base material(s)	
PF-1	Polymer fiber (after manufacturing)	
PF-2	Polymer fiber (after post processing)	
cPF-1	Covered polymer fiber (after covering)	
cPF-2	Covered polymer fiber (after post processing)	
cPFT	Covered polymer textile	
2W-SMPF-1	Two-way shape memory polymer fiber (after manufacturing)	
2W-SMPF-2	Two-way shape memory polymer fiber (after post processing)	
2W-cSMPF-1	Covered two-way shape memory polymer fiber (after covering)	
2W-cSMPF-2	Covered two-way shape memory polymer fiber (after post processing)	
2W-SMT-1	Two-way shape memory polymer textile (post manufacturing)	
2W-SMT-2	Two-way shape memory polymer textile (after post processing)	

PL1..PL6	Process layer (1 to 6)
P	Fiber production process 1 (extrusion/solution spinning/melt spinning)
FP1	Fiber post-processing 1
5 FP2	Fiber post-processing 2
CV1	Fiber covering process 1
CV2	Fiber covering process 2
PC1	Fiber post covering process 1
PC2	Fiber post covering process 2
10 TM1	Textile manufacturing process 1
TM2	Textile manufacturing process 2
TP1	Textile post processing 1
TP2	Textile post processing 2

15 Claims

1. A two-way shape memory textile (2W-SMT) (1), comprising:

a) a base fabric (1.1) formed from a plurality of base fibers (1.2), wherein the base fabric (1.1) comprises a shape memory area (1.3), and wherein the base fabric (1.1) is adapted to a surface contour (2.0),
b) wherein the shape memory area (1.3) comprises of one or more two-way covered shape memory polymeric fiber(s) (2W-cSMPFs) (3.0) integrated with or intertwined in the base fabric (1.1), the 2W-cSMPF (3.0) comprising

- a two-way shape memory polymeric fiber (2W-SMPF) (3.1) having at least a base state (S₀), a first (S₁), and a second programmed state (S₂), and
- the 2W-cSMPF (3.0) is switchable between the base state (S₀) and a programmed state (S₁/S₂) by an external stimulus (E₀); and between the first programmed state (S₁), the second programmed state (S₂) and vice versa by a further external stimulus (E₁/E₂), and
- a covering element (3.2) wound around the 2W-SMPF (3.1),

c) wherein a contraction or expansion of the 2W-cSMPF (3.1) induces a corresponding size change of the shape memory area (1.3) of the base fabric (1.1),

characterized in that

the covering element (3.2) limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF (3.0) in first programmed state (S₁) and/or second programmed state (S₂) to a value between 100% and 800% and below the elongation at break (ϵ_{break}) of the 2W-SMPF, the base fabric (1.1) is reversibly contracted or

- expanded in the shape memory area (1.3) by the 2W-cSMPF (3.0) by the further external stimulus (E_1/E_2), preferably by 2.5% to 200%.
2. The two-way shape memory textile (2W-SMT) (1) of claim 1, wherein the 2W-SMT (1) provides a compression pressure (5.0) to the surface contour (2.0), wherein the compression pressure (5.0) exerted by the 2W-SMT (1) in the second programmed state (S_2) is lower than the compression pressure in the first programmed state (S_1).
 3. The two-way shape memory textile (2W-SMT) (1) of claim 1 or 2, wherein the external stimulus E_0 and the further external stimulus (E_1/E_2) are selected independently from the list consisting of thermal, electromagnetic, electric, or light stimulation.
 4. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 3, wherein the further external stimuli E_1 and E_2 are different stimuli and each selected independently from the list consisting of thermal, electromagnetic, electric, or light stimulation.
 5. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 4, wherein the further external stimuli E_1 and E_2 are thermal stimuli, the programming temperature (T_{prog}) being in a range from -20°C to 90°C , and wherein the thermal stimuli are separated by a temperature difference (ΔT) of at least 20°C .
 6. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 5, wherein the 2W-cSMPF (3.0) comprises a two-way shape memory polymer selected from the list comprising or consisting of semi-crystalline polyesters, ethylene-co-monomer-polymers, di- or multi-block-co-polymers, or semi-crystalline ionomers.
 7. The two-way shape memory textile (2W-SMT) (1) of claim 6, wherein the two-way shape memory polymeric fiber (2W-SMPF) (3.1) comprises or consists of a 2W-SMP selected from the list consisting of polycaprolactone (PCL), cross-linked poly[ethylene-co-vinyl acetate] (cPEVA), poly(ethylene-1-octene), polycyclooctene containing trans-polyocentamer (PCO/TOR), poly[ethylene-co-ethyl acrylate-co-maleic anhydride] (PEEAMA), poly[ethylene-co-(methyl acrylate)-co-(glycidyl methacrylate)] (PEMAGMA), perfluorosulphonic acid ionomer (PFSA), amorphous multi block cycloaliphatic polyetherurethane (PEU) consisting of poly(tetramethylene glycol) (PTMEG), 1,4 butanediol (1,4-BD) and methylene bis(p-cyclohexyl isocyanate) (H12MDI).
 8. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 7, wherein the two-way shape memory polymeric fiber (2W-SMPF) comprises magnetically active fillers.
 9. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 8, wherein the two-way shape memory polymeric fiber (2W-SMPF) (3.1) comprises an electrically conductive material, preferably electrically conductive nanoparticles (ENPs), electrically conductive particles, electrically conductive coating(s) or as electrically conductive core-shell system.
 10. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 9, wherein the covering element (3.2) comprises or consists of a material selected from the list consisting of cotton, wool, silk, linen, bamboo, viscose, lyocell, polyether-polyurea copolymers, acrylic, polyamide, polyester or a blend thereof.
 11. The two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 9, wherein the covering element (3.2) comprises an electrically conductive and/or electromagnetically heatable material.
 12. A method for producing a **two-way shape memory textile** (2W-SMT) (1) of any of the claims 1 to 11, comprising the steps of
 - a) providing a 2W-SMPF (3.1) by a sequence of a fiber production process (P) from base materials (BM), preferably by extruding or spinning, a fiber covering step (CV), wherein a covering element (3.2) is wound around the produced fibers at a rate of 300 to 6000 twists per meter, yielding produced covered fibers,
 - b) providing a base fiber (1.2) and/or a base fabric (1.1), preferably adapting the base fiber or base fabric to a predetermined surface contour; and
 - c) a textile manufacturing process, integrating or intertwining the covered produced fibers into the base fabric (1.1) and/or base fiber (1.2) to form a designated shape memory area (1.3),

characterized in that

at least one post-processing step (PF, PC, TP) introducing 2W-SM properties is provided in or after one of steps a) or c) wherein a post-processing step preferably comprises cross-linking, coating, compounding, or heat treatment, which correspondingly yields a 2W-SMPF (3.1), 2W-cSMPF (3.0) or 2W-SMT (1).

13. The method for producing a **two-way shape memory textile** (2W-SMT) (1) of claim 12, further com-

prising the step of:

d) programming a programmed state (S_1/S_2) of the 2W-SMPF by applying an external stimulus (E_0) under a predetermined set of conditions, preferably in conjunction with a step a) or c).

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14. A covered two-way shape memory polymeric fiber (2W-cSMPF) (3.0) according to any claims 1 to 13, comprising

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a) a two-way shape memory polymeric fiber (2W-SMPF) (3.1), having at least a base state (S_0), a first (S_1), and a second programmed state (S_2),

b) the 2W-cSMPF (3.0) is switchable between the base state (S_0) and a programmed state (S_1/S_2) by an external stimulus (E_0); and between the first programmed state (S_1), the second programmed state (S_2) and vice versa by a further external stimulus (E_1/E_2), and

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c) a covering element (3.2) wound around the 2W-SMPF (3.1), wherein the covering element (3.2) limits the maximum strain ($\epsilon_{\max}$) of the 2W-cSMPF (3.0) in first programmed state (S_1) and/or second programmed state (S_2) to a value between 100% and 800% and below the elongation at break (ϵ_{break}) of the 2W-SMPF (3.1), preferably determined at 10°C, and wherein the 2W-cSMPF (3.0) is contracted or expanded by the further external stimulus (E_1/E_2), preferably by 2.5% to 200%.

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15. A use of the two-way shape memory textile (2W-SMT) (1) of any of the claims 1 to 11 as a compression garment(6.0), wherein the 2W-SMT (1) provides a compression pressure of 0.5 to 8.5 kPa in a first programmed state (S_1).

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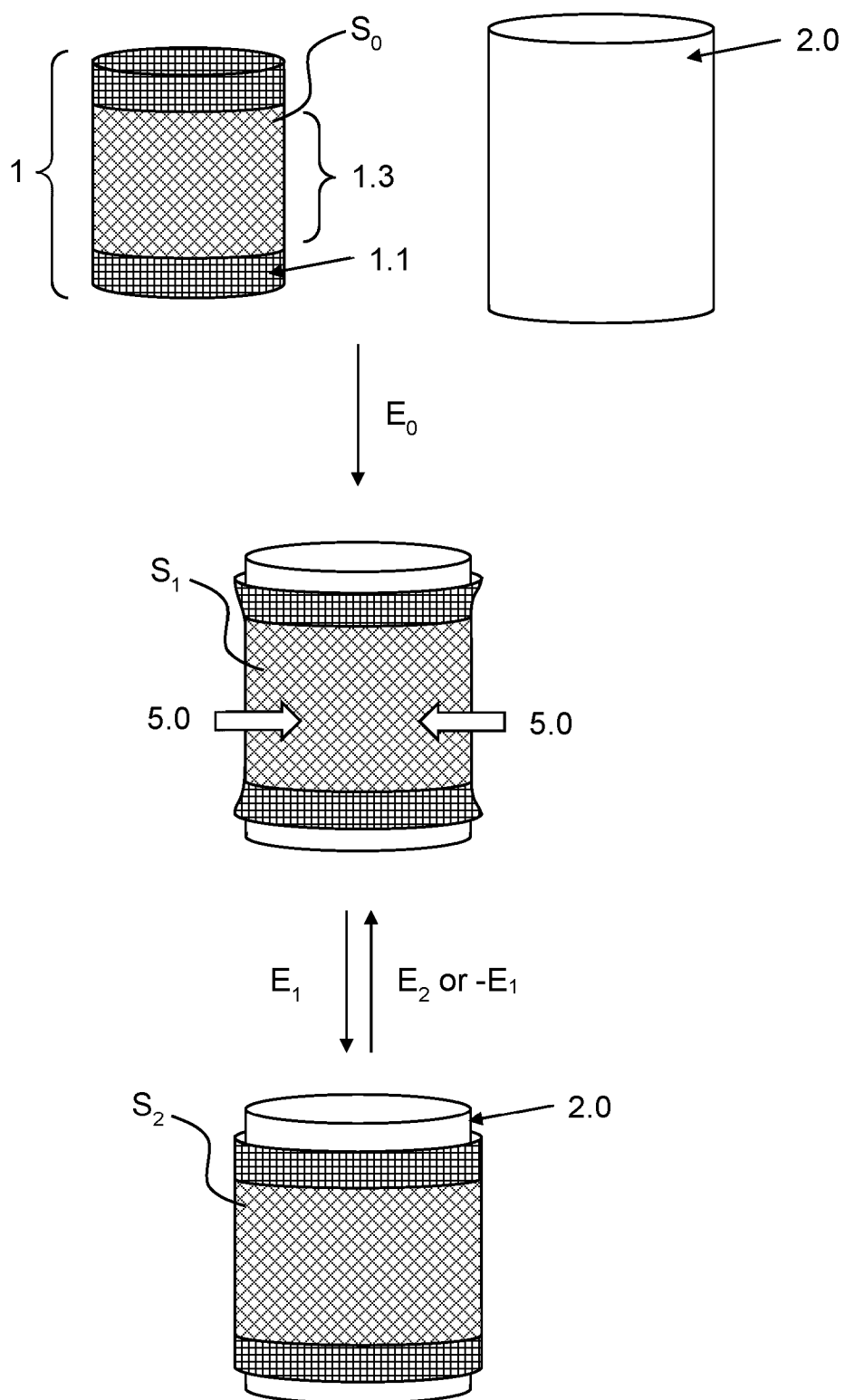


Fig. 1

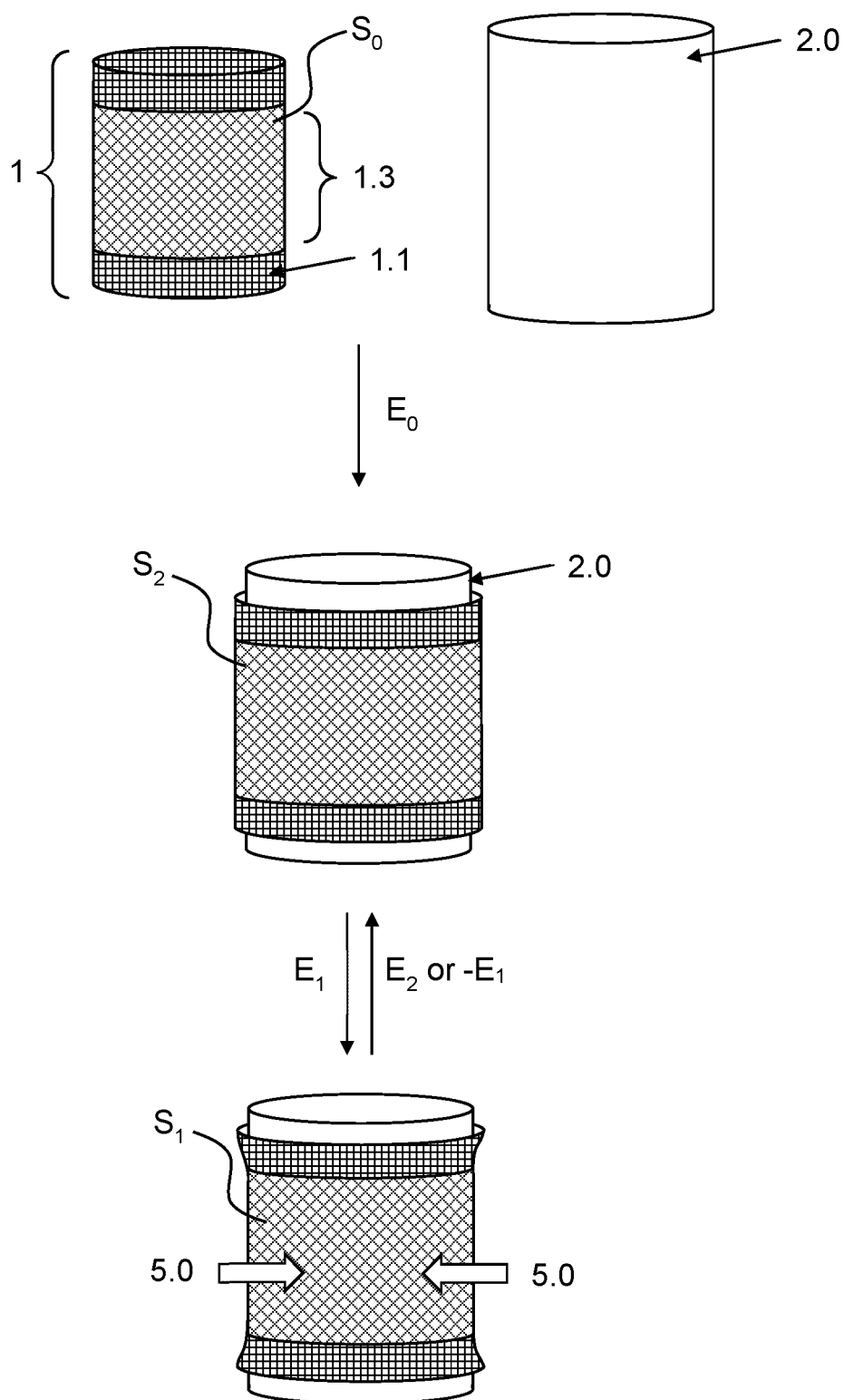


Fig. 2

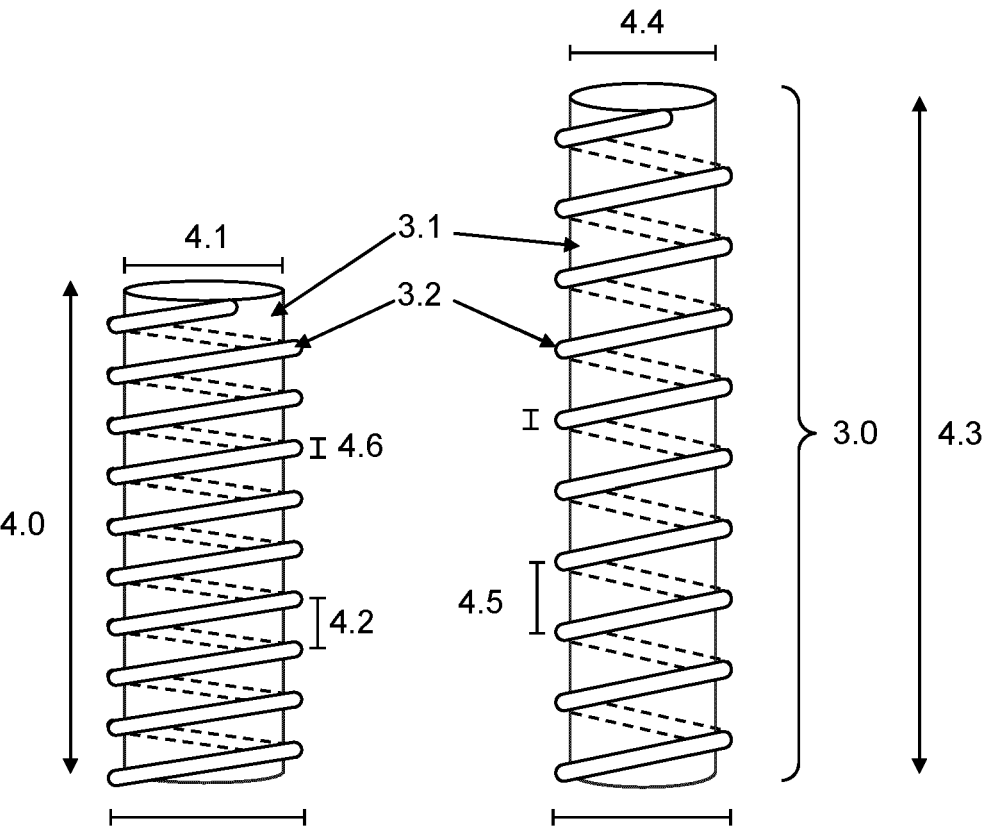


Fig. 3A

Fig. 3B

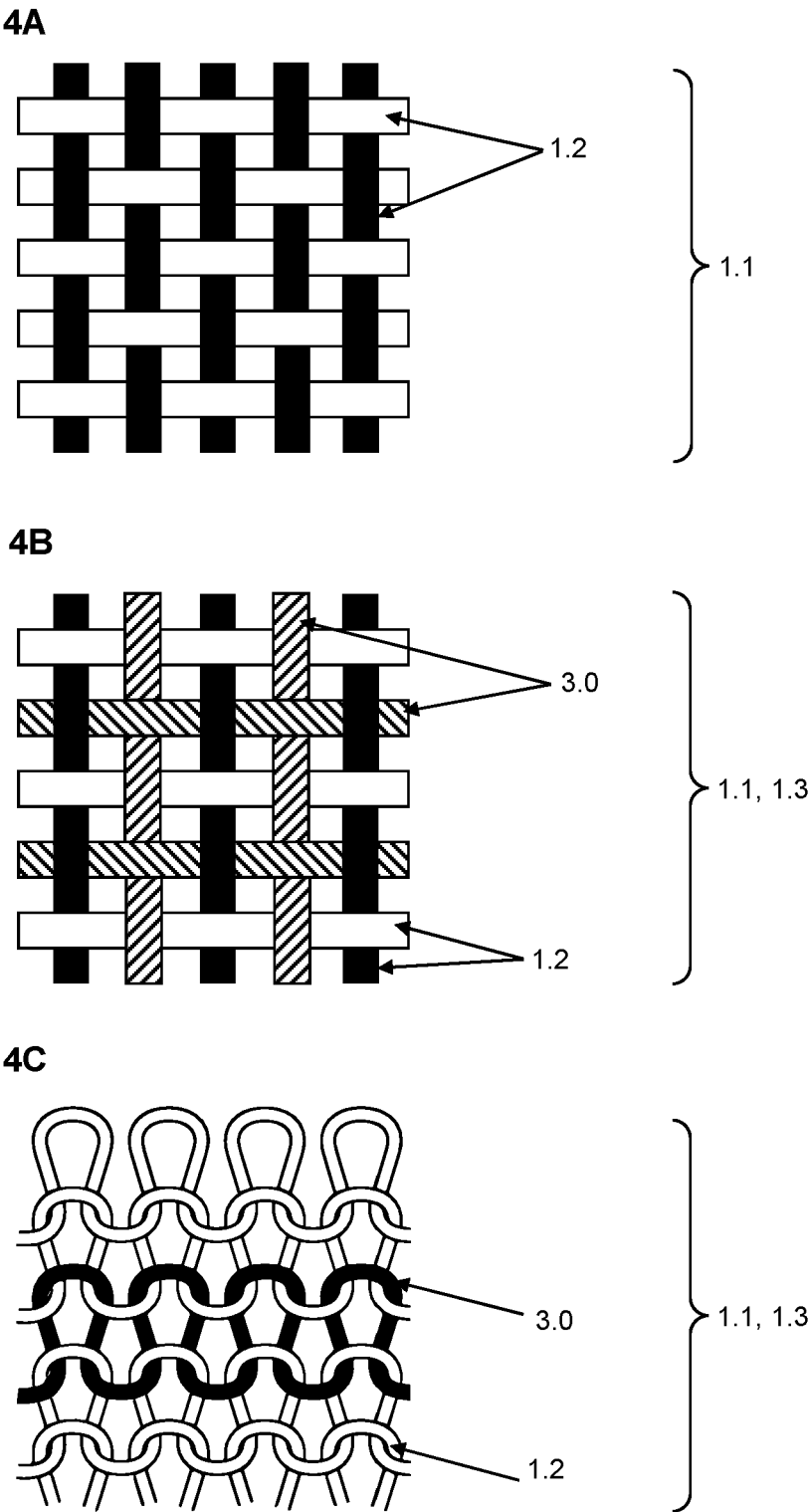


Fig. 4

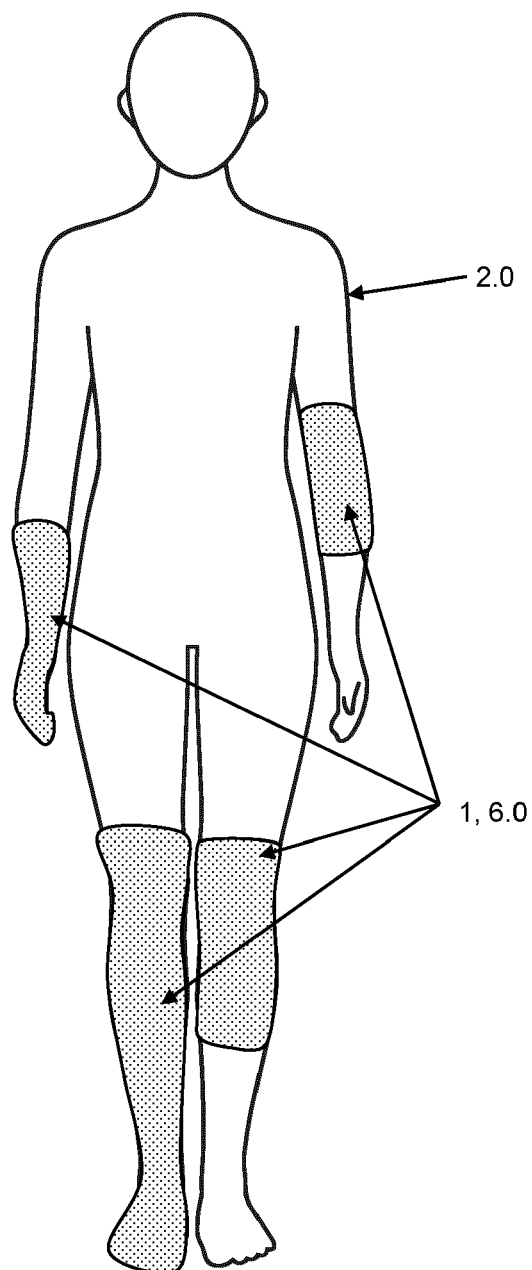


Fig. 5

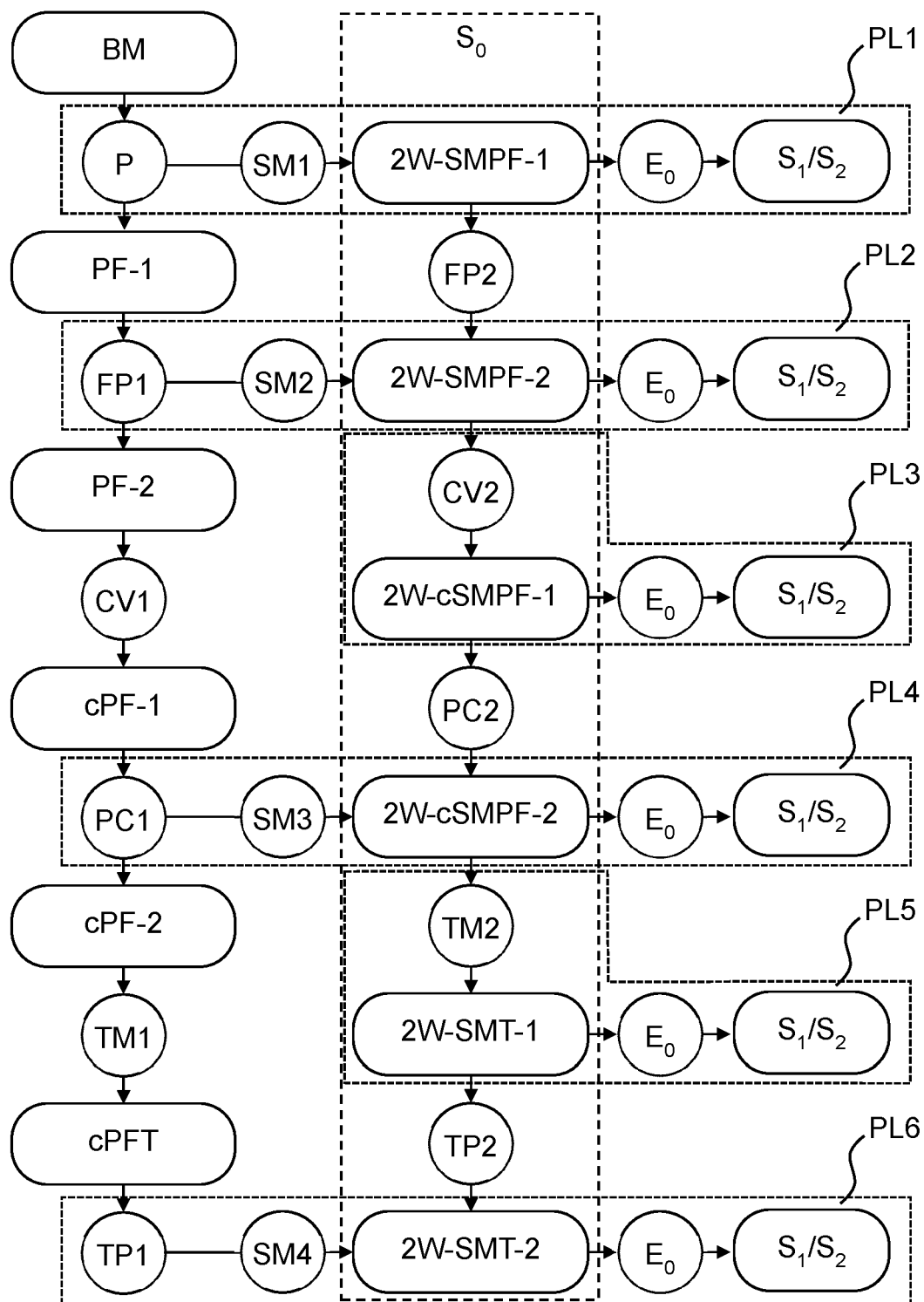


Fig. 6



EUROPEAN SEARCH REPORT

Application Number

EP 25 17 1251

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Y	EP 4 403 682 A1 (HELMHOLTZ ZENTRUM HEREON GMBH [DE]) 24 July 2024 (2024-07-24) * paragraph [0009] - paragraph [0012] * * paragraph [0016] - paragraph [0025] * * paragraph [0027] - paragraph [0029] * * paragraph [0043]; example 1 * * figures 1, 2 *	1-3, 5-10, 12-15	
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			D02G D03D
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		5 September 2025	Hausding, Jan
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

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