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(54) **ANISOTROPIC MAGNETORHEOLOGICAL ELASTOMER ARTICLE AND MANUFACTURING METHOD OF SAID ARTICLE**

(57) Anisotropic magnetorheological elastomer article comprising an elastomer matrix (1) and magnetic particles (2) distributed in the elastomer matrix (1). The article (10) is a plate formed by the elastomer matrix (1). The elastomer matrix (1) comprises a first layer (3a) with

magnetic particles (2) and a second layer (3b) without magnetic particles (2), such that the article (10) is bent if a magnetic field is applied in a direction perpendicular to said article (10).

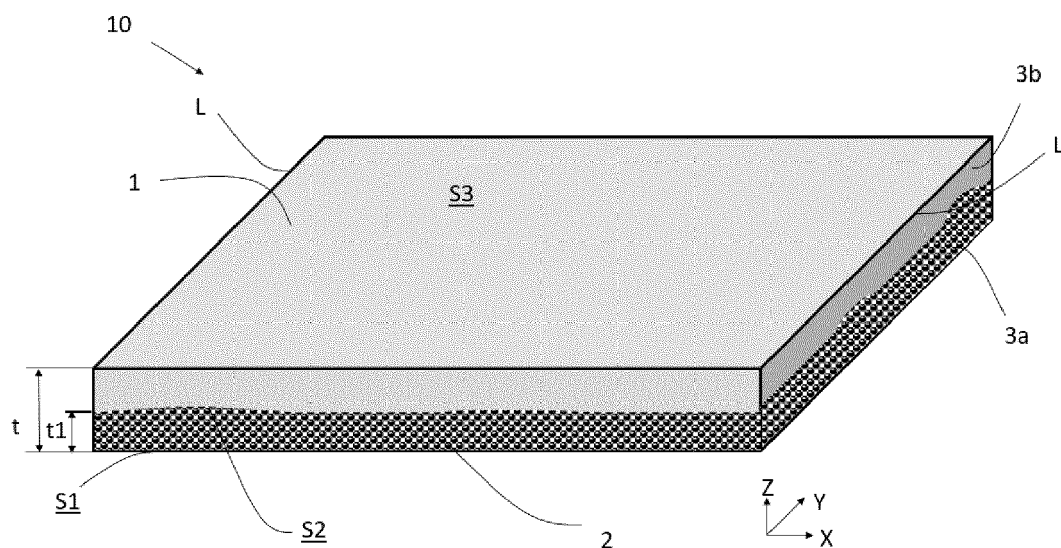


FIG. 2

Description

TECHNICAL FIELD

[0001] The present invention relates to anisotropic magnetorheological elastomer articles and to methods of manufacturing said article.

PRIOR ART

[0002] Magnetorheological elastomer (MRE) articles which comprise an elastomer matrix and magnetic particles distributed in the elastomer matrix and which, in the presence of a magnetic field, experience a change in rigidity and dimension due to the interaction between the magnetic particles which tend to be oriented in the direction of the external field applied, are known. In magnetorheological elastomer articles, the magnetic particles are distributed in a solid elastomer matrix, unlike magnetorheological fluids (MRF) in which the magnetic particles are suspended in a liquid fluid.

[0003] Anisotropic magnetorheological elastomer articles comprising an internal anisotropic distribution of magnetic particles to achieve a greater change of properties in one of the directions of the article when a magnetic field is applied are also known. For example, anisotropic magnetorheological elastomer articles in which the magnetic particles are oriented grouped into columnar or laminar structures by means of a magnetic field applied during the manufacturing thereof, are known.

[0004] Anisotropic magnetorheological elastomer articles are more difficult to manufacture, although they are more effective than isotropic magnetorheological elastomer articles which, unlike anisotropic elastomers, exhibit a homogenous distribution of magnetic particles.

[0005] CN110648815B discloses a manufacturing method of an anisotropic magnetorheological elastomer article which achieves a controlled axial distribution by separately solidifying magnetorheological elastomer blocks, each with a different content of magnetic particles, placing the solidified blocks in an organized manner according to the content of magnetic particles in the axial direction of the article, and attaching the different blocks to one another to give rise to the anisotropic magnetorheological elastomer article. Specifically, the disclosed article comprises eight blocks which are arranged in an ascending or descending manner according to the content of magnetic particles, with the content of magnetic particles of each block being comprised between 10% and 80%.

DISCLOSURE OF THE INVENTION

[0006] The object of the invention is to provide an anisotropic magnetorheological elastomer article, a manufacturing method of said article, and the use of said article, as defined in the claims.

[0007] One aspect of the invention relates to an aniso-

tropic magnetorheological elastomer article comprising an elastomer matrix and magnetic particles distributed in the elastomer matrix. The article is a plate formed by the elastomer matrix. The elastomer matrix comprises a first layer with magnetic particles and a second layer without magnetic particles, such that the article is bent if a magnetic field is applied in a direction perpendicular to said article.

[0008] The article is therefore formed by a single elastomer matrix comprising two adjacent layers: a layer which is active with respect to the magnetic field, i.e., the first layer with the magnetic particles, and a layer which is inactive with respect to the magnetic field, i.e., the second layer without magnetic particles.

[0009] In the article of the invention, the first layer and the second layer are not attached to one another, rather the article is formed by a single elastomer matrix, with the first layer and the second layer belonging to said single solidified elastomer matrix. Therefore, the article of the invention is an article that is free of attachment defects wherein external stresses, such as a magnetic field, do not weaken the integrity of the article. This fact, along with the first layer being active with respect to the magnetic field and the second layer being inactive with respect to the magnetic field, ensures a greater interaction between said layers than if each layer belongs to a separately solidified elastomer matrix.

[0010] The article of the invention is a simpler and more effective alternative than anisotropic magnetorheological elastomer articles known in the state of the art because a significant change of properties is achieved with only two layers of a single elastomer matrix that are active and inactive with respect to the magnetic field.

[0011] The way in which the article behaves in the presence of a magnetic field is different from that of the anisotropic magnetorheological elastomer articles of the state of the art. In the articles of the state of the art, the dimension of the article changes in the direction of the applied magnetic field, as illustrated in Figure 1. However, the article of the invention is bent if a magnetic field is applied in a direction perpendicular to the article.

[0012] Another aspect of the invention relates to a method of manufacturing an article like the one defined above. The method comprises a first addition step of adding a liquid elastomer, the magnetic particles, and additives in a mold, and a second solidification and distribution step in which the additives solidify the liquid elastomer giving rise to the elastomer matrix, whereas an external force distributes the magnetic particles in the liquid elastomer before the solidification thereof ends, generating the first layer and the second layer.

[0013] The method of manufacturing an article like the one defined above is simple and economical.

[0014] Another aspect of the invention relates to the use of the article of the invention for flow control.

[0015] These and other advantages and features of the invention will become apparent in view of the figures and the detailed description of the invention.

DESCRIPTION OF THE DRAWINGS

[0016]

Figure 1 shows an anisotropic magnetorheological elastomer article of the state of the art, in the absence of a magnetic field and when a magnetic field is applied.

Figure 2 shows a perspective view of an anisotropic magnetorheological elastomer article of the invention according to a preferred embodiment, in the absence of a magnetic field.

Figure 3 shows a perspective view of the article of Figure 2, when a magnetic field is applied in a direction perpendicular to the article.

Figure 4 shows a perspective view of an anisotropic magnetorheological elastomer article of the invention according to another embodiment.

Figure 5 shows a schematic depiction of the addition step of the manufacturing method of the invention according to one embodiment.

Figure 6 shows a schematic depiction of the start and end of the solidification and distribution step of the manufacturing method of the invention according to one embodiment.

DETAILED DISCLOSURE OF THE INVENTION

[0017] The article 10 of the invention comprises an elastomer matrix 1 and magnetic particles 2 distributed in the elastomer matrix 1, as shown in Figure 2. The article 10 of the invention is characterized in that it is a plate formed by the elastomer matrix 1. The elastomer matrix 1 comprises a first layer 3a with magnetic particles 2 and a second layer 3b without magnetic particles 2. In other words, the article 10 is formed by a single elastomer matrix 1 which comprises two adjacent layers: a layer which is active with respect to the magnetic field H, i.e., the first layer 3a with the magnetic particles 2, and a layer which is inactive with respect to the magnetic field H, i.e., the second layer 3b without magnetic particles 2. Therefore, the first layer 3a and the second layer 3b comprise a common interface S2.

[0018] The elastomer matrix 1 is not a magnetorheological fluid but rather a solid matrix.

[0019] In the preferred embodiment illustrated in Figure 2, the article 10 is a plate that is substantially planar in directions X and Y in the absence of a magnetic field $H=0$ and has a thickness t in direction Z, so the first layer 3a and the second layer 3b also extend along directions X and Y. The common interface S2 is an irregular longitudinal surface, as shown in Figure 2. The article 10 further comprises side faces L and a first outer surface S1

which, together with the common interface S2 and the side faces L, demarcate the first layer 3a, and a second outer surface S3 which, together with the common interface S2 and the side faces L, demarcate the second layer 3b.

[0020] In the article 10 of the invention, the first layer 3a and the second layer 3b are not attached to one another, rather the article 10 is formed by a single solidified elastomer matrix 1, with the first layer 3a and the second layer 3b belonging to said single elastomer matrix 1. Therefore, the article 10 is an article that is free of attachment defects wherein external stresses, such as a magnetic field, do not weaken the integrity of the article 10. This, along with the first layer 3a being active with respect to magnetic field and the second layer 3b being inactive with respect to the magnetic field, ensures a greater interaction between said layers than if each layer belongs to a separately solidified elastomer matrix.

[0021] The article 10 of the invention is a simpler and more effective alternative than anisotropic magnetorheological elastomer articles known in the state of the art because a significant change of properties is achieved with only two layers of a single elastomer matrix that are active and inactive with respect to the magnetic field.

[0022] The article 10 behaves differently in the presence of a magnetic field as compared to anisotropic magnetorheological elastomer articles of the state of the art. In the articles of the state of the art, the dimension of the article changes in the direction of the applied magnetic field, as illustrated in Figure 1. However, the article 10 of the invention is bent if a magnetic field H is applied in a direction perpendicular to the article 10.

[0023] The applied magnetic field H having a component in said direction perpendicular to the article 10 is enough for the article 10, which is substantially planar in the absence of a magnetic field $H=0$, to acquire a bent shape. However, the greater said component of the magnetic field H is in the direction perpendicular to the article 10, the more the article 10 will bend.

[0024] In the preferred embodiment shown in Figures 2 and 3, the direction perpendicular to the article 10 is direction Z. If the magnetic field H is applied to the article 10 in direction Z, the article 10 is bent in said sense in direction Z. The shape into which the article 10 is bent depends on the geometry thereof. In the case of the article 10 with a geometry like the one shown in Figure 2, if the magnetic field H is applied to the article 10 in a positive sense in direction Z, i.e., from the first layer 3a which is active with respect to magnetic field to the second layer 3b which is inactive with respect to the magnetic field, the article 10 and the outer surfaces S1 and S3 are bent in said positive sense in direction Z as shown in Figure 3. If the magnetic field H is applied in the negative sense in direction Z, i.e., from the second layer 3b which is inactive with respect to the magnetic field to the first layer 3a which is active, the article 10 would be bent in said negative sense in direction Z.

[0025] In a preferred embodiment, the magnetic parti-

cles 2 of the article 10 are arranged oriented arbitrarily in the absence of magnetic field $H=0$. The article 10 is therefore more economical to manufacture than anisotropic magnetorheological elastomer articles of the state of the art because it does not require expensive equipment for arranging the magnetic particles 3 such that they are oriented with a specific orientation during the manufacturing thereof.

[0026] In a preferred embodiment, the magnetic particles 2 of the article 10 are soft ferromagnetic particles. Soft ferromagnetic particles are characterized in that they return to their initial position and orientation on their own when the applied magnetic field H is eliminated, i.e., they are reversible. They have a high magnetic saturation, hardly any magnetic hysteresis, and can be readily magnetized and demagnetized. The article 10 is therefore reversible, i.e., it can acquire the initial curvature on its own after eliminating the applied magnetic field H as a result of the reversible characteristics of the magnetic particles 2 and of the elastomer matrix 1.

[0027] In a preferred embodiment, the article 10 has a thickness t of less than 2 mm. The magnetic field H required for bending the article 10 is therefore lower.

[0028] In a preferred embodiment, the first layer 3a has a thickness t_1 of between 10 and 90% of the thickness t of the article 10. This thereby ensures that both layers 3a and 3b have a minimum thickness t_1 of 10% of the thickness t of the article 10. In the preferred embodiment shown in Figure 2, the thickness t_1 of the first layer 3a is the same as the thickness of the second layer 3b, i.e., the thickness t_1 of the first layer 3a is 50% of the thickness t of the article 10.

[0029] In a preferred embodiment, the content by weight of the magnetic particles 2 is between 10 and 70% of the content by weight of the article 10, preferably 60%. It has been proven that the article 10 must have at least 10% of the content by weight of the magnetic particles 2 for the article 10 to have sufficient bending capacity. The higher the content by weight of the magnetic particles 2 are, the greater the bending capacity of the article 10 in the presence of one and the same magnetic field H . However, it has been proven that, beyond 70% of the content by weight of the magnetic particles 2, the bending capacity of the article 10 does not increase, but only increasing the cost of the raw material.

[0030] In a preferred embodiment, the elastomer matrix 1 is a synthetic rubber, polyvinyl chloride, or silicone elastomer. In the preferred embodiment shown in Figures 2 and 3, the elastomer matrix 1 is a silicone elastomer. The elastomer matrix 1 is therefore capable of being cured at low temperatures and it is also cured quickly at high temperatures. Furthermore, liquid silicone elastomer has a low viscosity, making it easier to form. The dynamic viscosity of the silicone elastomer used in one embodiment is 1.2 Pa.s.

[0031] In a preferred embodiment, the magnetic particles 2 have a size greater than 50 μm . Therefore, the magnetic particles 2 can be more readily concentrated

in the magnetically active layer 3a or 3b. The magnetic particles 2 can be in a spherical or amorphous shape. In comparison with the spherical shape, the amorphous shape may be beneficial to achieve high degrees of packing of the magnetic particles 2 and to thereby enable obtaining high concentrations of magnetic particles 2 in the magnetically active layer 3a or 3b of a certain thickness t_1 .

[0032] Figure 4 shows a second embodiment of the article 10 according to the invention. This embodiment differs from the preferred embodiment described above in that two side faces L of the article 10 are attached such that the article 10 forms a tube. In other words, the article 10 is tubular, adopting said shape as a result of the hypothetical attachment of two side faces L of the plate shown in Figure 2. Therefore, in this embodiment, a direction perpendicular to the article 10 is a direction perpendicular to the tube, i.e., a direction perpendicular to the direction of extension of the tube, and the article 10 is bent if the magnetic field H is applied in said direction. The rest of the features are identical to those described for the article 10 of the preferred embodiment, so they are not described again.

[0033] As mentioned above, the shape into which the article 10 is bent depends on the geometry thereof. In the case of a tubular geometry of the article 10 like the one shown in Figure 4, the tubular article 10 extends in direction Z and has a circular section in the absence of a magnetic field. The article 10 is bent, adopting an elliptical section if a magnetic field H is applied in the direction perpendicular to direction Z . The greater the magnetic field H that is applied, the smaller the length of the minor axis of the elliptical section, and therefore the smaller the passage cross-section through the tube will be, where the passage cross-section may even be non-existent or substantially non-existent.

[0034] Another aspect of the invention relates to a manufacturing method of the article 10, the method comprising the following steps:

- a first addition step of adding a liquid elastomer 4, the magnetic particles 2, and additives 5 in a mold 6, and
- a second solidification and distribution step in which the additives 5 solidify the liquid elastomer 4 giving rise to the elastomer matrix 1, whereas an external force F distributes the magnetic particles 2 in the liquid elastomer 4 before the solidification thereof ends, generating the first layer 3a and the second layer 3b.

[0035] The manufacturing method of the article 10 does not require expensive equipment or subsequent steps which increase the cost of and complicate the manufacturing method of the article 10 to achieve an anisotropic distribution of magnetic particles 2 such as, for example, a subsequent attachment step.

[0036] Figure 5 and Figure 6 schematically show the

addition step and the solidification and distribution step of an embodiment of the method of the invention. The mold 6 comprises a cavity in the shape of a plate having a thickness t in which the magnetic particles 2 and the liquid elastomer 4 are added together with the additives 5.

[0037] Adding the elastomer 4 in liquid state increases the mobility of the magnetic particles 2 for their suitable distribution. The additives 5 mainly comprise vulcanizers which activate the curing and solidification of the liquid elastomer 4 in the mold 6. However, the additives 5 may also comprise other non-magnetic components, for example, plasticizing agents. On one hand, the vulcanizers polymerize the liquid elastomer 4, forming increasingly more cross-linked bonds which hinder the movement of the magnetic particles 2 and give rise, at the end of the curing process, to the solid elastomer matrix 1, and on the other hand, the plasticizing agents increase the mobility of the magnetic particles 2 in the liquid elastomer 4, aiding to enable the suitable distribution of the magnetic particles 2 during the curing and solidification of the liquid elastomer 4.

[0038] At the start of the distribution and solidification step of this embodiment in which the additives 5 have yet to start the solidification of the liquid elastomer 4, the magnetic particles 2 are suspended in the liquid elastomer 4 throughout the entire cavity of the mold 6, as shown in Figure 6A.

[0039] The external force F is preferably a non-magnetic external force that does not require expensive equipment for generating said force. A magnetic force which orients the magnetic particles during the solidification of the elastomer matrix would increase the cost of the method significantly.

[0040] In an embodiment of the method, the external force F is the gravitational force, such that the gravitational force causes the magnetic particles 2 to settle in the liquid elastomer 4, as shown in Figure 6B. The settling speed becomes slower as more cross-linked bonds are being formed in the liquid elastomer 4 during the curing process. The gravitational force allows the magnetic particles 2 to be concentrated in the lower portion of the mold 6 before the solidification of the liquid elastomer ends, the first layer 3a with the magnetic particles 2 being the layer of the article 10 which is arranged in the lower portion of the mold 6. The solidification and distribution step therefore does not require any equipment for generating the force F which distributes the magnetic particles 2.

[0041] In another embodiment of the method not shown in the figures, the mold 6 comprises a cavity in the shape of a tube and the external force F applied is a centrifugal force. The external force F can therefore be generated in a simple and inexpensive manner.

[0042] In an embodiment of the method, the method comprises at least one mixing step before the addition step in which the liquid elastomer 4, the magnetic particles 2, and the additives 5 are mixed under pressure outside the mold 6. In this manner, when mixing is performed under pressure, air bubbles which are detrimental

to the properties of the article 10 are eliminated and a homogenous mixture of the additives 5 and of the magnetic particles 2 in the liquid elastomer 4 which is ready to be introduced in the mold 6 is obtained.

[0043] In an embodiment of the method, the liquid elastomer 4 has a dynamic viscosity of less than 5 Pa.s. The mobility of the magnetic particles 2 in the liquid elastomer 4 for their suitable distribution is thereby favored.

[0044] Another aspect of the invention relates to the use of an article 10 described above for flow control, for example, as a part of a flow control valve or pump. The different behavior of the article 10 in the presence of a magnetic field enables said use in a particularly advantageous manner.

Claims

1. Anisotropic magnetorheological elastomer article comprising an elastomer matrix (1) and magnetic particles (2) distributed in the elastomer matrix (1), **characterized in that** the article (10) is a plate formed by the elastomer matrix (1) comprising a first layer (3a) with magnetic particles (2) and a second layer (3b) without magnetic particles (2), such that the article (10) is bent if a magnetic field (H) is applied in a direction perpendicular to said article (10).
2. Article according to claim 1, wherein the magnetic particles (2) are arranged oriented arbitrarily in the absence of magnetic field.
3. Article according to claim 1 or 2, wherein the magnetic particles (2) are soft ferromagnetic particles.
4. Article according to any of the preceding claims, wherein the article (10) has a thickness (t) of less than 2 mm.
5. Article according to any of the preceding claims, wherein the first layer (3a) has a thickness (t_1) of between 10 and 90% of the thickness (t) of the article (10), preferably 50%.
6. Article according to any of the preceding claims, wherein the content by weight of the magnetic particles (2) is between 10 and 70% of the content by weight of the article (10), preferably 60%.
7. Article according to any of the preceding claims, wherein the elastomer matrix (1) is a synthetic rubber, PVC, or silicone elastomer.
8. Article according to any of the preceding claims, wherein the magnetic particles (2) have a size greater than 50 μm .
9. Article according to any of the preceding claims,

wherein two side faces (L) of the article (10) are attached such that the article (10) forms a tube.

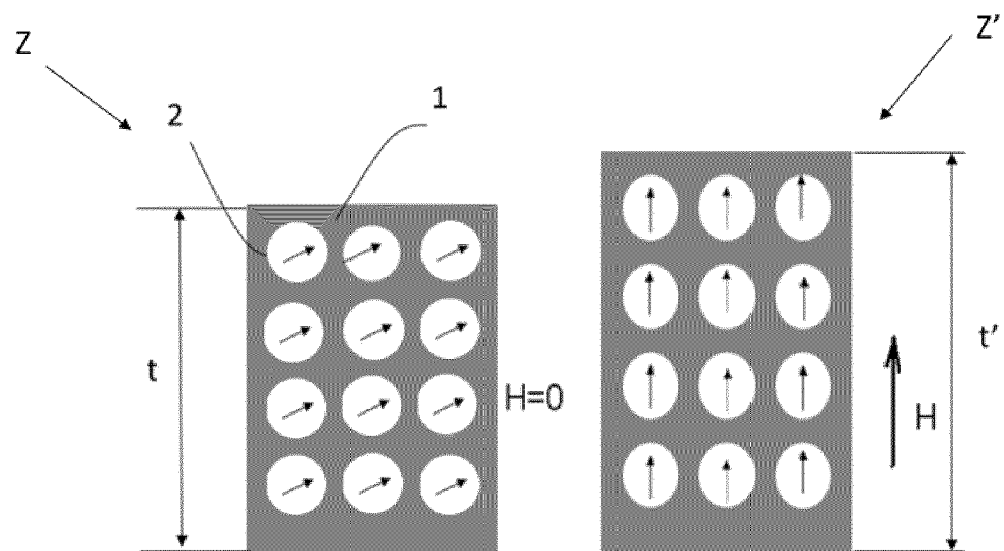
10. Manufacturing method of an article according to any of the preceding claims, the method comprising 5
 - a first addition step of adding a liquid elastomer (4), the magnetic particles (2), and additives (5) in a mold (6), and
 - a second solidification and distribution step in 10which the additives (5) solidify the liquid elastomer (4) giving rise to the elastomer matrix (1), whereas an external force (F) distributes the magnetic particles (2) in the liquid elastomer (6) before the solidification thereof ends, generating 15the first layer (3a) and the second layer (3b).
11. Manufacturing method according to claim 10, wherein the external force (F) is the gravitational force, such that the gravitational force causes the magnetic 20particles (2) to settle in the liquid elastomer (4).
12. Manufacturing method according to claim 10 or 11, the method comprising at least one mixing step before the addition step in which the liquid elastomer 25(4), the magnetic particles (2), and the additives (5) are mixed under pressure outside the mold (6).
13. Manufacturing method according to any of claims 10 to 12, wherein the liquid elastomer (4) has a dynamic viscosity of less than 5 Pa.s. 30
14. Use of an article according to any of claims 1 to 9 for flow control. 35

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Prior art

FIG. 1

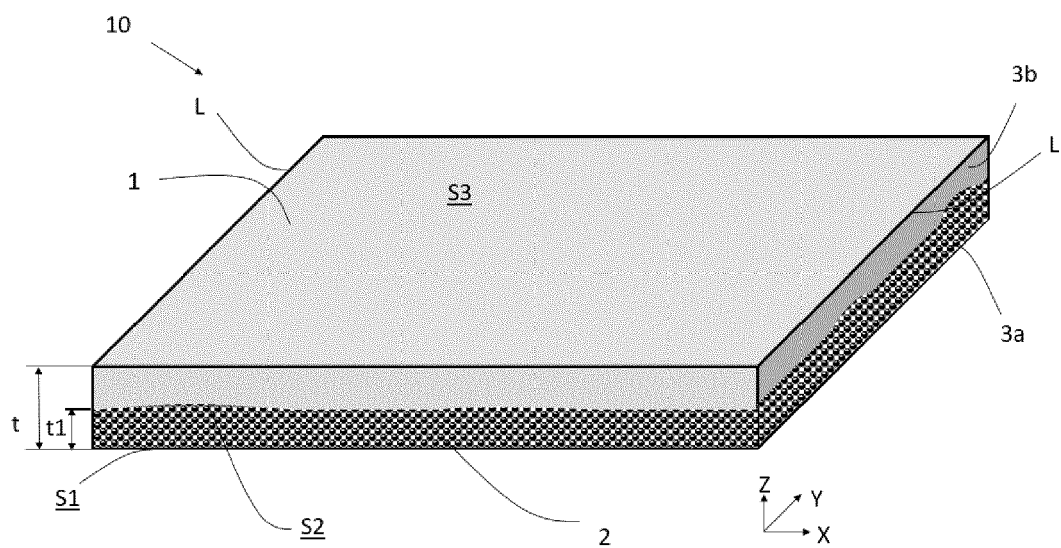


FIG. 2

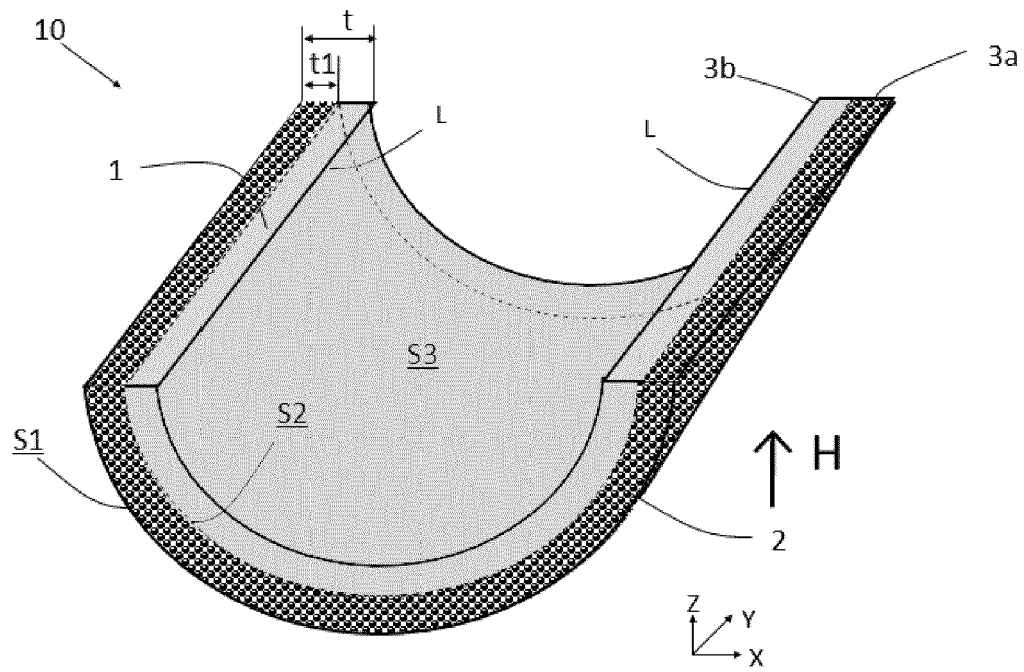


FIG. 3

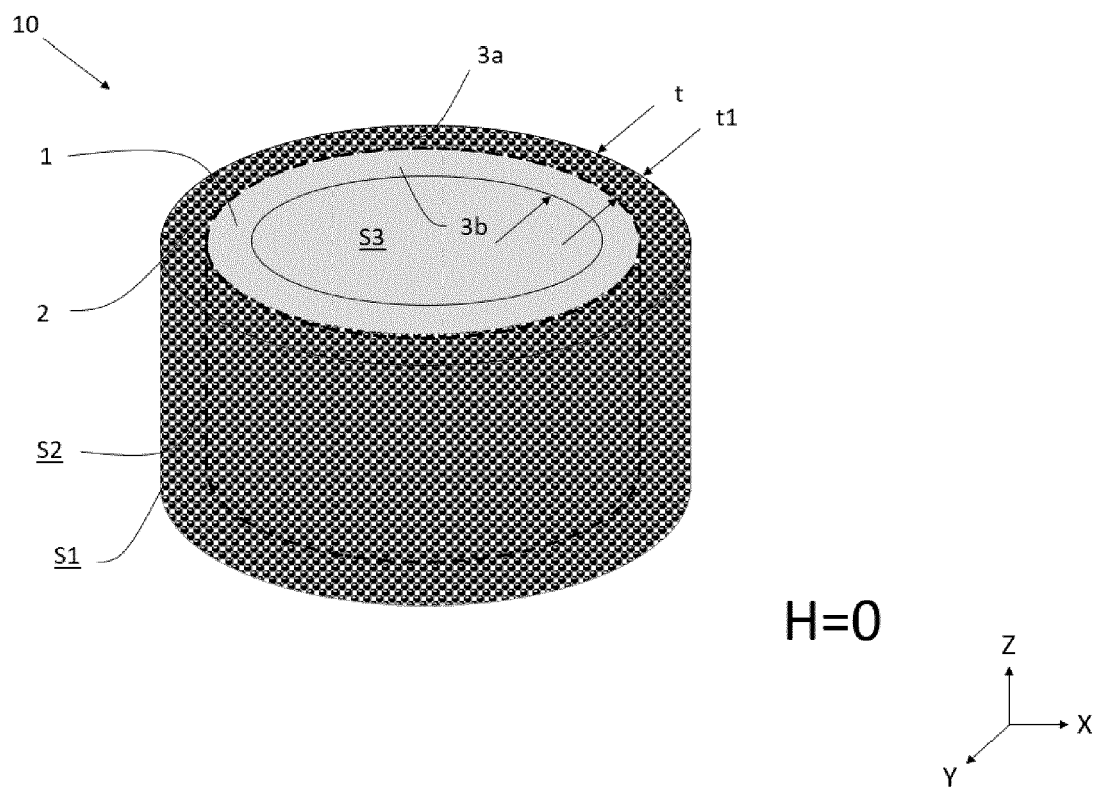


FIG. 4

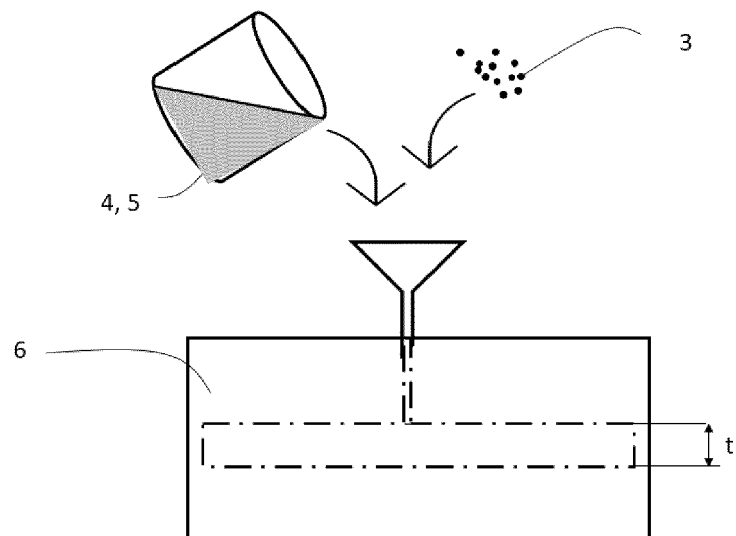


FIG. 5

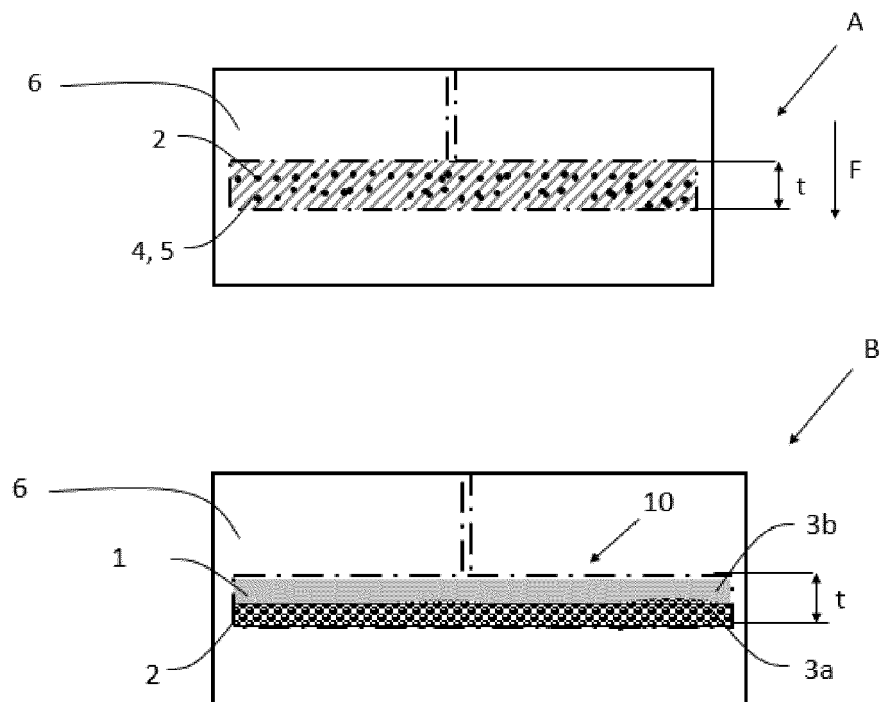


FIG. 6



EUROPEAN SEARCH REPORT

Application Number

EP 21 38 3051

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EPO FORM 1503 03.82 (P04C01)

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