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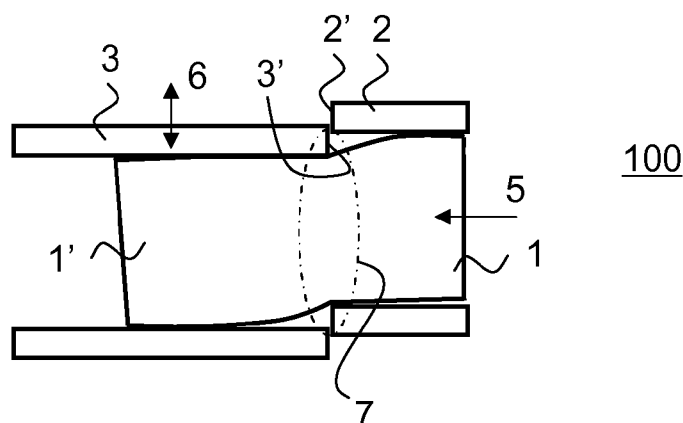


FIG. 4

(57) Abstract: A SPD process comprising deforming metal material (1) in an apparatus (100) which comprises a material flow-through channel (2, 3, 4) which is arranged in a first direction (5), and a press (3). The method comprises feeding metal material (1) in the first direction (5) so that the material need not be in a state of extreme stress, and pressing the material reciprocally by the press (3) in at least one second direction (6) which is crosswise relative to the first direction, and deforming grain size of the material smaller. An apparatus (100) for deforming metal material (1) to SPD material.



SPD PROCESS AND APPARATUS

FIELD OF THE INVENTION

- 5 The invention relates to a SPD process and an apparatus. Particularly, though not exclusively, the invention relates to manufacturing nano and UFG (Ultra Fine Grained) metals with the SPD method (Severe Plastic Deformation) by reducing grain size of the materials.

10 BACKGROUND OF THE INVENTION

- Durability and loadability of products are based on material properties and form of the product. An effective way to increase competitiveness of technology industry manufacturing is to develop reliable, cheap and flexible production technologies
15 which are improving quality and usability of the product. The SPD method (Severe Plastic Deformation) is one new and effective way for improving the properties of the product at the production phase.

- In SPD methods, a heavy deforming is taking place during the production at the
20 same time giving shape for the product and reducing the grain size of the material to micron range. It has been sought to produce UFG materials, that is, fine grained materials with SPD methods in test circumstances. UFG materials are called in this connection also microstructured materials. The grain size may typically be under 1 μm in a microstructured material (the grain size of conventional alloys may
25 be 20 to 100 μm).

- Reducing the grain size improves substantially, among others, the mechanical properties. Microstructured products have diverging properties and property combinations: for example, high strength, good fatigue resistance, persistence and
30 corrosion resistance and good further manufacturability (machinability, superplastic properties). Properties of a microstructured product can be changed by thermal processing: the grain size and properties can be changed in a body location specifically.

The range of use of microstructured products is broad such as space technology, transport technology, devices and components relating to health care, sports equipment, food and chemical industry, electronics and defense sector.

5 Microstructured bolts are used among others in automobile and aircraft industry. Microstructured materials are also well suitable for micro bolts, for example. The advantages of the small grain size are exploited also in pistons of combustion engines as well as in sputtering objects utilized in growing of thin films. Due to the clean and strong material the microstructured materials can be used also in
10 implants.

A known application of the SPD method is ECAP (Equal Channel Angular Pressing) according to which a rod-like or bar-like piece is compressed into a channel having one or more corners. An axial compression and shear is directed
15 to the material in the angle of the channel where the structure of the material is deformed.

A SPD method is known of WO 2006/100448 A1 where metal is processed in order to change the mechanical and/or physical properties of the metal. In the
20 method, the grain size of the metal is reduced by feeding a metal piece through a first channel to a second channel which is inclined in relation to the first channel. The metal piece is deformed by repeating the load directed to the metal piece using at least one reciprocating movement in the intersection of the first and second channels.

25

A further application of the ECAP method is known from the patent publication RO123274 B1. An extreme axial stress state is generated to a small diameter metal bar by compressing the bar axially in the method, after which the bar is deformed by plastic shearing in one or more cross sections. The plastic
30 deformation is made perpendicular to the axial direction. Two hydraulic cylinders are fixed to the piece to be compressed axially in order to provide the axial stress state.

The publications presented in the following are related to deformation of the microstructure of metal material.

5 A. Azushima, R. Kopp, A. Korhonen, D.Y. Yang, F. Micari, G.D. Lahoti, P. Groche, J. Yanagimoto, N. Tsuji, A. Rosochowski, A. Yanagida, Severe Plastic Deformation (SPD) Processes for Metals, Keynote Lecture, 58th CIRP General Assembly, 24 – 30 August, 2008, Manchester, U.K., 22 p.

10 T. Manninen, K. Kanervo, A. Revuelta, J. Larkiola and A. S. Korhonen, Plastic deformation of solderless press-fit connectors, 9th International Conference on Technology of Plasticity, ICTP 2005, Verona, October 9 – 13, 2005. 9 p., Materials Science and Engineering A 460 – 461 (2007) 633-637.

15 Jari Kokkonen, Veli-Tapani Kuokkala, Lech Olejnik, Andrzej Rosochowski, Dynamic behavior of ECAP processed aluminum at room and sub-zero temperatures, SEM XI International Congress & Exposition on Experimental and Applied Mechanics, Orlando, Florida USA, June 2 - 5, 2008.

20 V-T. Kuokkala, J. Kokkonen, B. Song, W. Chen, L. Olejnik and A. Rosochowski, Dynamic Response of SPD Processed 1070 Aluminum at Various Temperatures, 18th Dymat Technical Meeting, 10-12.9.2008, Bourges, France.

25 Production of microstructured products made of SPD metals takes nowadays place in laboratory circumstances or in small scale production. Raw materials and billets made of SPD metals are today not manufactured by means of industrial mass production. This is mainly caused by the reason that a well operating SPD process suitable for a continuous process is not known.

30 An object of the invention is to provide an alternative SPD process. A second object of the invention is to provide an apparatus for deforming metal with the SPD process. An object of the invention is to enable production of SPD materials as full-scale products. An object of the invention is to enable production of SPD materials with a continuous process. An object of the invention is to provide a SPD

process suitable for industrial production, particularly for UFG metals. An object of the invention is to provide a SPD process suitable for industrial production, particularly for nano and UFG metals.

5 SUMMARY

According to a first example aspect of the invention there is provided a SPD process comprising deforming metal material in an apparatus which comprises a material flow-through channel which is arranged in a first direction, and a press,
10 and the method comprising feeding metal material in the first direction and pressing the material reciprocatively by the press in at least one second direction which is crosswise relative to the first direction, and deforming grain size of the material smaller.

15 According to a second example aspect of the invention there is provided a SPD process comprising deforming metal material in an apparatus which comprises a material flow-through channel which is arranged in a first direction, and a press, and the method comprising feeding metal material in the first direction so that the material need not be in a state of extreme stress, and pressing the material
20 reciprocatively by the press in at least one second direction which is crosswise relative to the first direction, and deforming grain size of the material smaller.

Preferably the material is not pressed or pushed or bended or pulled or twisted in a deformation location in any direction or to any direction in that phase when it is
25 started to deform the material. By the statement that the material need not be in a state of extreme stress is preferably meant that the material is not pressed or pushed or bended or pulled or twisted in a deformation location in any direction or to any direction in that phase when it is started to deform the material.

30 Preferably the press comprises a press channel which is forming part of the flow-through channel.

Preferably deforming the material in a shearing processing between shearing

tools. The shearing tools are preferably arranged at edges of on one hand the press (press channel) movable in the second direction, and on other hand of a section (which is stationary, for example) of the flow-through channel neighbouring to the press.

5

Preferably deforming material such that the shearing is not lead till cut-off.

Preferably repeating deforming of the material in the same pressing location.

10 Preferably repeating deforming of the material in different directions of the material. The material may be lead repeatedly through the SPD processing.

15 Preferably pressing the material perpendicularly relative to the feeding direction of the material. The same effect may be provided also by a rotational pressing perpendicular to the material. Preferably pressing the material in a different direction relative to the feeding direction of the material.

20 Preferably feeding the material in the first direction through the flow-through channel which comprises an inlet channel and thereafter a press channel which are arranged in the first direction, and forming a material deforming deformation force by moving the press channel reciprocatively relative to the feeding direction (first direction, inlet channel) in at least one second direction.

25 Preferably feeding the material in the first direction through the flow-through channel which comprises an inlet channel and an outlet channel and the press channel between thereof which are arranged in the first direction, and forming a material deforming deformation force by moving the press channel reciprocatively relative to the feeding direction (first direction, inlet channel) and an outlet direction (outlet channel) in at least one second direction.

30 Preferably deforming the material in a first pressing region which is formed by a leaving end of an inlet direction (inlet channel) and a starting end of the press (press channel).

Preferably deforming the material in a second pressing region which is formed by a leaving end of the press (press channel) and a starting end of an outlet channel (outlet direction).

- 5 Preferably feeding the material cyclic in the first direction. Preferably pressing reciprocatively the material cyclic by the press in the second direction.

Preferably deforming the grain size of the material mainly to a range 0.1 to 1 μm for producing UFG material, and under 0.1 μm for producing nano material, most
10 preferably through the entire material. By the process the material may naturally be deformed such that a substantial portion of the material comprises for example material of grain size 0.1 to 1 μm and part of the material may then have larger grain size and part of the material may then have smaller grain size. If a smaller deformation is targeted, by the process the material may naturally be deformed
15 such that the material is deformed lesser than what is desired in order to obtain for example UFG material.

Preferably feeding the material continuously in the first direction and pressing the material continuously by moving the press of the apparatus reciprocatively in the
20 second direction or in alternative directions depending on the shape of the piece such as circularly.

Preferably returning the deformed material to the same location in line with the inlet channel where the material was before starting of the deformation.

25

Preferably cold forming the material after the SPD deforming for example by cold rolling.

According to a third example aspect of the invention there is provided an
30 apparatus for deforming metal material to SPD material which apparatus comprises a material flow-through channel which is arranged in a first direction, and a press, and the flow-through channel comprises a material inlet channel and thereafter the press in which inlet channel and press the material is arranged to be

moved in the first direction, and the apparatus is configured to press the material reciprocatively by the press relative to the inlet channel in a second direction which is crosswise relative to the first direction.

- 5 According to a fourth example aspect of the invention there is provided an apparatus for deforming metal material to SPD material which apparatus comprises a material flow-through channel which is arranged in a first direction, and a press, and the flow-through channel comprises a material inlet channel and thereafter the press in which inlet channel and press the material is arranged to be
- 10 moved in a first axial direction so that the material need not be in a state of extreme stress, and the apparatus is configured to press the material reciprocatively by the press relative to the inlet channel in a second direction which is crosswise relative to the first direction.

- 15 Preferably the apparatus comprises shearing tools which are arranged at edges of on one hand the press movable in the second direction, and on other hand of a part of the flow-through channel adjacent to the press.

- Preferably the press comprises a press channel which is forming part of the flow-
- 20 through channel after the inlet channel.

Preferably a leaving end of the inlet channel and a starting end of the press channel are forming at their location a first pressing region.

- 25 Preferably the flow-through channel comprises in the first direction an outlet channel after the press channel, and an outlet end of the press channel and a starting end of the outlet channel are forming at their location a second pressing region. This is, though, not necessary but a deformation is achieved already by one pressing region.

30

Preferably the material is arranged to be moved reciprocatively in the second direction supported by the press, more preferably by the press chamber.

Preferably the apparatus is arranged to direct to the material a shearing deformation force so that the shearing is not lead till cut-off.

5 According to preferable embodiments of the invention there is achieved an entirely new process and apparatus wherein a controlled shearing state can be achieved in the material so that an inner structure of a continuous piece to be deformed is changed and the piece keeps united (without disintegrating).

10 According to preferable embodiments of the invention by the process and the apparatus the material can be deformed in a pure shearing reciprocatively in a second direction relative to the axial (feeding) direction which second direction is perpendicular relative to the axial (feeding) direction. Then, the material need not be in a state of extreme stress.

15 One has been able to increase the productive and uninterrupted duration of a continuous material deformation process by inventing that is not necessary to press the piece to be deformed in a state of extreme stress. Therefore many drawbacks associated with the prior art can be avoided.

20 Moving of the continuous body in the axial direction can be implemented controlled and accurate in a desired manner. Forwarding of the body in the axial direction, i.e., true feeding in the axial direction is simple and easy to get desired.

25 The extreme axial stress of the material to be deformed known in the prior art is associated with the conception of the conventional ECAP method where the material is held united, during the shearing event, by a large compressing force.

30 According to preferable embodiments of the invention wearing of shearing tools (particularly edge/side of the tool) can be slowed down substantially compared to a situation in which the extreme stress would be directed to the body to be deformed. When the body to be deformed is axially in a non-stressed state, the wearing forces directed mainly to a working edge of the deforming tool will stay substantially smaller compared to a situation in which the body would be arranged

in a state of axial extreme stress. Damaging caused by axial sticking of the outer surface of the body can also be avoided.

5 The apparatus implementing the process can be designed simple without the property implementing the axial compression.

According to a preferable embodiment of the invention there is provided a continuous material deforming process comprising steps: feeding a continuous piece (with a minor force), holding the piece stationary (with a minor force),
10 deforming the piece by shearing which is crosswise relative to the axial direction, feeding etc.

According to a preferable embodiment of the invention there is provided a production mode for different cross section shapes, also for sheet-like bodies.

15 Preferably in the process and apparatus all trajectories are numerically controllable for forming a desired SPD material.

The described cyclic SPD process is providing an industrially reasonable
20 production manner which is creating a possibility to achieve competitive advantage by producing metal products having a smaller grain size and for which a well working industrial process was prior not known. An industrial production process for mass production can be achieved with the described solutions. The described solutions are providing alternative ways to implement the SPD method.

25 The cyclic pressing process described by the applicant enables production of nano and UFG materials with the SPD method so that the production manner is suitable for large production volumes cost effectively. The described production manner enables production of micro and nano structured materials.

30 The SPD process implemented as a cyclic pressing process is suitable for an industrial production process for nano and UFG metals.

By utilizing preferable embodiments of the invention it is possible to achieve such industrial scale production technology which, along production and development of new developed materials, enables production of better environment saving products. The process can be applied for all metal materials. In some cases, the structure of a product, produced by the process and the apparatus, may be compacted such that stress corrosion is decreasing.

Microstructured products can be used on a large area practically in all structures, components and products in which metal is used such as supporting and bearing structures, motors and parts thereof, transmissions such as gears, general metal structures, space technology, lightweight structure technology, vehicles, vehicles operating in water, flight apparatuses, transportation technology, devices and components relating to health care, protective devices, sports equipment, food and chemical industry, defense sector such as weapons and projectiles.

Different embodiments of the present invention will be illustrated or have been illustrated only in combination with one or some aspects of the invention. A person skilled in the art understands, that any embodiment of one aspect of the invention may be applied in the same aspect of the invention and in other aspects alone or as a combination with other embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described, by way of example, with reference to the accompanying schematical drawings, in which:

Fig. 1 shows a principal view of a SPD apparatus according to a first embodiment of the invention where the SPD method is applied;

Fig. 2 shows the SPD apparatus of Fig. 1 where material is fed to a centre part and the material is deformed in a reciprocating movement of the centre part in one region;

Fig. 3 shows the SPD apparatus of Fig. 1 where the material is deformed in the reciprocating movement of the centre part in one or two regions; and

Fig. 4 shows a principal view of a SPD apparatus according to a second embodiment of the invention where material is deformed in one region.

DETAILED DESCRIPTION

5

In the following description, like numbers denote like elements. It is possible to implement the described process with many different apparatus configurations and it is not expedient to begin illustrating all of them. It should be appreciated that the illustrated drawings are not entirely in scale, and that the drawings mainly serve
10 the purpose of illustrating some example embodiments of the invention.

Figs. 1 to 3 show a principal view of an apparatus 100 which is applying the SPD method.

15 Metal material 1 is deformed in the SPD apparatus 100 for forming, for example, UFG or nano material. The apparatus 100 comprises a material flow-through channel arranged in a first direction 5 comprising an inlet channel 2 and an outlet channel 4, and a press channel 3 (a press) arranged to a centre part of the apparatus between the inlet channel and the outlet channel, in which inlet channel,
20 press channel and outlet channel the material 1 is arranged to be moved in the first direction 5. During the deforming, the material need not be in a state of extreme stress. The press channel 3 is moved reciprocally in a second direction 6 relative to the inlet channel and the outlet channel which other direction is crosswise relative to the first direction 5. A leaving end 2' of the inlet channel 2 and
25 a first end 3' of the press channel 3 are forming at their location a first pressing region 7 and a second end 3'' of the press channel 3 and a starting end 4' of the outlet channel 4 are forming at their location a second pressing region 8. The grain size of the material 1 can be deformed by one or two pressing regions to size under 1 μm , preferably 0.1 to 1 μm or more in case of nano materials. Preferably
30 the material is moved supported by the press channel 3. Preferably the material is moved reciprocally in at least one second direction 6. The reciprocative movement is up and down movement in Figs. 1 to 3.

Preferably the apparatus comprises guide rollers 9 for feeding the material in the flow-through channel 2, 3, 4. The material can be pushed or fed by means of the guide rollers. If desired, the billet can also be rotated during the process. Naturally, the material can be deformed entirely in the first pressing region 7 so that a
5 reciprocally shearing pressing is generated in the material which, however, does not lead to cut-off of the material.

In the phase of the process shown in Fig. 1, a front end 1' of the material 1 is fed in the first direction 5 via the inlet channel 2 for deformation to the centre part
10 formed by the press channel 3. The material is supported in the inlet channel and the reciprocative pressing of the material is started by the centre part moving in the second direction 6 and the material is fed cyclic forward. The apparatus comprises guide rollers 9 for guiding the material to the apparatus 100.

15 In the phase of the process shown in Fig. 2, the front end 1' of the material is fed in the first direction 5 for deformation to the centre part formed by the press channel 3 and the material is pressed in second direction 6 by the reciprocally moving centre part and fed cyclic forward. The centre part is forming the press wherein the material is deformed in the first pressing region denoted with a dashed
20 line 7.

In the phase of the process shown in Fig. 3, the front end 1' of the material is lead in the first direction 5 through the press channel 3 to the outlet channel 4. The material is deformed in the second direction 6 by the reciprocally moving centre
25 part and fed cyclic forward. The centre part is forming the press wherein the material is deformed in the first pressing region denoted with a dashed line 7 and the second pressing region denoted with a dashed line 8.

It should be emphasized that the deformation can be intensified in the pressing
30 regions 7, 8 by moving the press 3 in the same location in the reciprocative direction several times and returning the material 1 to the same centre location as before starting of the deformation.

Fig. 4 shows an SPD apparatus 100 in which the material 1 is deformed in one pressing and shearing region. The apparatus of Fig. 4 is lacking, relative to the apparatus of Fig. 2, the outlet channel after the press 3 (pressing channel). Thus, the material is deformed only in the first pressing region 7.

5

The foregoing description provides non-limiting examples of some embodiments of the invention. It is clear to a person skilled in the art that the invention is not restricted to details presented. Some features of the described embodiments may be utilized without all other features.

10

As such, the foregoing description shall be considered as merely illustrative of the principles of the invention, and not in limitation thereof. Hence, the scope of the invention is only restricted by the appended patent claims.

PATENT CLAIMS

1. A SPD process comprising deforming metal material (1) in an apparatus (100) which comprises a material flow-through channel (2, 3, 4) which is arranged in a first direction (5), and a press (3), **characterized** in that the method comprising feeding metal material (1) in the first direction (5) so that the material need not be in a state of extreme stress, and pressing the material reciprocally by the press (3) in at least one second direction (6) which is crosswise relative to the first direction, and deforming grain size of the material smaller.

10

2. The process according to claim 1, **characterized** by deforming the material (1) in a shearing processing between shearing tools (2', 3'; 3'', 4').

3. The process according to claim 1 or 2, **characterized** by deforming the material (1) in a shearing processing such that the shearing is not lead till cut-off.

15

4. The process according to any of claims 1 to 3, **characterized** by repeating deforming of the material (1) in the same pressing location (7, 8).

5. The process according to any of claims 1 to 4, **characterized** by repeating deforming of the material (1) in different directions of the material.

20

6. The process according to any of claims 1 to 5, **characterized** by pressing the material (1) in a different direction (6) relative to the feeding direction (5) of the material.

25

7. The process according to any of claims 1 to 6, **characterized** by feeding the material (1) in the first direction (5) through the flow-through channel which comprises an inlet channel (2) and thereafter a press channel (3) which are arranged in the first direction, and forming a material deforming deformation force by moving the press channel (3) comprised by the press (3) reciprocally relative to the feeding direction (5) in at least one second direction (6).

30

8. The process according to claim 7, **characterized** by feeding the material (1) in the first direction (5) through the flow-through channel which comprises an inlet channel (2) and an outlet channel (4) and the press channel (3) between thereof which are arranged in the first direction, and forming a material deforming deformation force by moving the press channel (3) reciprocatively relative to the feeding direction and an outlet direction in at least one second direction (6).

9. The process according to any of claims 1 to 8, **characterized** by deforming the material in a first pressing region (7) which is formed by a leaving end (2') of the inlet channel (2) and a starting end (3') of the press (3).

10. The process according to any of claims 1 to 9, **characterized** by deforming the material in a second pressing region (8) which is formed by a leaving end (3'') of the press channel (3) and a starting end (4') of the outlet channel (4).

15

11. The process according to any of claims 1 to 10, **characterized** by returning the deformed material (1) to the same location in line with the inlet channel (2) where the material was before starting of the deformation.

12. The process according to any of claims 1 to 11, **characterized** by rotating the material during the feeding.

13. The process according to any of claims 1 to 12, **characterized** by cold forming the material after the SPD deforming.

25

14. An apparatus (100) for deforming metal material (1) to SPD material which apparatus comprises a material flow-through channel (2, 3, 4) which is arranged in a first direction (5), and a press (3), **characterized** in that the flow-through channel (2, 3, 4) comprises a material inlet channel (2) and thereafter the press (3) in which inlet channel and press the material is arranged to be moved in a first axial direction (5) so that the material need not be in a state of extreme stress, and the apparatus is configured to press the material reciprocatively by the press relative to the inlet channel in a second direction (6) which is crosswise relative to the first

30

direction.

15. The apparatus according to claim 14, **characterized** in that the apparatus comprises shearing tools which are arranged at edges of on one hand the press
5 (3) movable in the second direction (6), and on other hand of a part (2, 4) of the flow-through channel adjacent to the press.

16. The apparatus according to claim 14 or 15, **characterized** in that the press
10 comprises a press channel (3) which is forming part of the flow-through channel after the inlet channel (2).

17. The apparatus according to claim 16, **characterized** in that a leaving end
(2') of the inlet channel (2) and a starting end (3') of the press channel (3) are
forming at their location a first pressing region (7).

15

18. The apparatus according to claim 17, **characterized** in that the flow-
through channel (2, 3, 4) comprises in the first direction (5) an outlet channel (4)
after the press channel (3), and an outlet end (3'') of the press channel (3) and a
starting end (4') of the outlet channel are forming at their location a second
20 pressing region (8).

19. The apparatus according to any of claims 14 to 18, **characterized** in that
the material (1) is arranged to be moved reciprocatively in the second direction (6)
supported by the press (3).

25

20. The apparatus according to any of claims 14 to 19, **characterized** in that
the apparatus is arranged to direct to the material (1) a shearing deformation force
so that the shearing is not lead till cut-off.

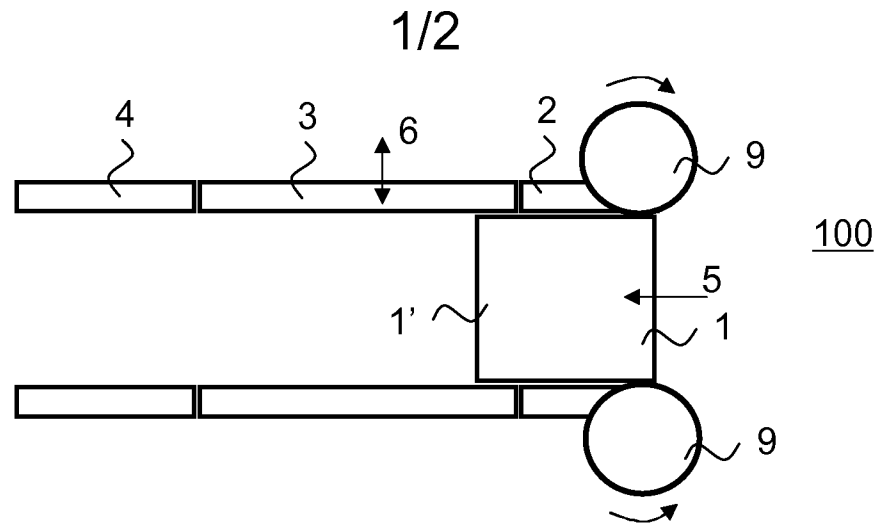


FIG. 1

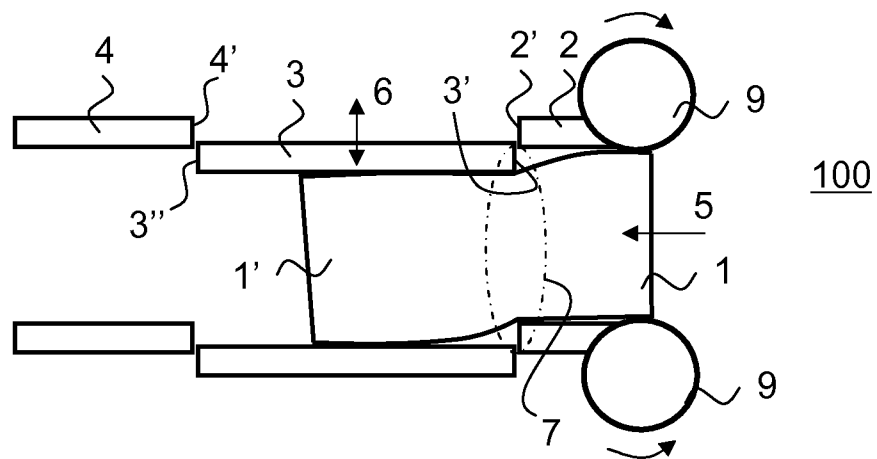


FIG. 2

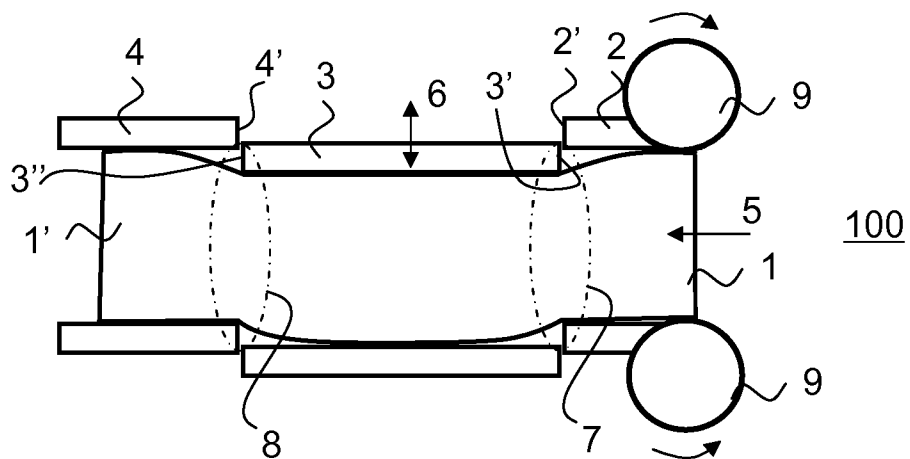


FIG. 3

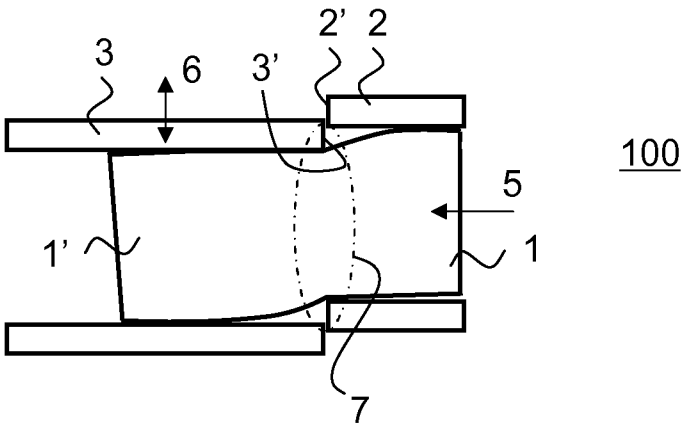


FIG. 4