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(54) Title: COMPOSITE PRODUCTION METHOD WITH CONTINUOUS SQUEEZE CAST METAL MATRIX

(57) Abstract: The invention describes a continuously squeezed metal matrix composite (MMK) material production method and a machine developed to carry out said continuous production. The homogeneous distribution structuring and solidification control under pressure, inside a rotational moving compressor and under atmospheric and thermal controlled conditions of continuous, non-continuous and powder reinforcement materials into a metal matrix is carried out by means of the system that has been developed; and as a result continuous production having plate, cylindrical and tube formed items with variable wall thicknesses is performed.

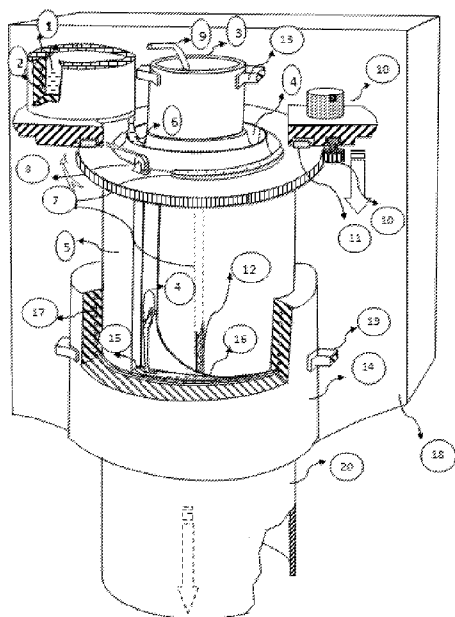


Figure 1

DESCRIPTION

COMPOSITE PRODUCTION METHOD WITH CONTINUOUS SQUEEZE CAST METAL MATRIX

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Technical Field of the Invention

The invention describes a continuously squeezed metal matrix composite (MMK) material production method and a machine developed to carry out said continuous production. The homogenous distribution structuring and solidification control under pressure, inside a rotational moving compressor and under atmospheric and thermal controlled conditions of continuous, non-continuous and powder reinforcement materials into a liquid metal matrix is carried out by means of the system that has been developed; and as a result continuous production having plate, cylindrical and tube formed items with variable wall thicknesses is performed.

15 Known State of the Art (Prior Art)

Products with high added value are provided by using high quality materials during production. Nowadays improved materials are used in advanced technology products. The rapid development of technology has also increased the anticipated performance requirements from materials. This demand has significantly accelerated the developments of new materials. Another field where developments can be observed is the field of composite materials. With the application of metal matrix materials, properties of classical materials have been increased by up to 100%. For example; silver-diamond materials have become cooling platforms in technology products with a value of 600 W/mK, aluminium-ceramic fibre materials have provided high thermal resistance and fourth generation nanocomposite applications have already started to be used in defence sector. Thanks to new mixing applications and new production techniques that are developed day by day; new features and performances have been achieved with the use of highly qualified materials in sectors such as the defence sector, air transportation, automotive and health sectors and in information systems.

Metal matrix composites (Low density, high strength, thermal advantage, thermal stability, etc.) have been used increasingly due to their superior properties as mentioned above. For example;

it has been used in many applications such as space shuttles, ballistic missile applications, highly destructive explosives, high speed aircraft applications, advanced auto brake discs, pistons and aircraft landing gears.

Current production techniques are an important factor which limits the expected development in terms of cost and product variety. Some of these systems that have been developed in laboratories in the recent years have found widespread usage in the industry. In particular, casting based operations are preferred due to cost advantages and industry experience, and processes have been applied faster. The high cost of powder metal technique used in the production of metal matrix composites have led to the development of cast matrix applications.

However some problems are still faced in classic cast composite applications. Some of these problems can be listed as follows;

- Floating or precipitation due to density differences in fluids,
- Non-homogenous distribution of additives in the matrix,
- Low viscosity due to the ratio of additives and reinforcement materials,
- Thermal expansion differences of matrix and reinforcement materials,
- Strength loss due to surface wetting,
- Dimensional limitations (regarding homogenous distribution),
- Fibre deformation in mixing systems,
- Agglomeration during mixing,
- Generally non-continuous production,
- Interfacial reactions,
- Pores due to solidification precipitation,

Advanced material requirements can be met by using these defect reducing production techniques. In order to reach this aim, said problems have been tried to be overcome by means of using matrix compliant ceramics as reinforcement materials, surface wetting and forming a strong binding structure, pre-casting, mixing and high pressing force. Casting applications are important for the development of these composites both economically and practically. Although semi-solid compaction casting used to reduce such problems have shown the tendency to overcome some of these problems, the need for high power and the limited ability to produce different shaped pieces has reduced production tonnage.

The present shape of the product, the type of components, type and ratio of components, matrix alloy, particle shape, production method are differentiated by means of secondary processes etc.; therefore they also show differences in terms of their internal structures and strengths. The liquid, liquid-solid phase metal matrix composite forming techniques have been listed as liquid casting matrix composite production methods such as pressurized or non pressurized infiltration, semi solid composite casting (compocasting), mixing (vortex), reinforcement of liquid by gas injection, squeezing casting and liquid spray. Liquid matrix has been used in these techniques and the application method shows differences. Squeezing is carried out at a certain mass in single shaped moulds. The production is carried out basically in liquid phase, liquid-solid and solid (reaction in situ) form. The applications of the known state of the art are as follows:

1: Solid phase production techniques: These are mechanisms where the matrix and reinforcement materials are generally solid at the beginning and heat is used during combining such as sintering.

- Powder metal applications: Conventional sintering, plasma sintering, hot press, hot extrusion, deformation processing, semi solid powder processing,
- Thermal spraying: Plasma spraying, HVOF spraying, cold kinetic spraying.
- Other applications: Mixing at the molecular level, sandwich processing, CVD/PVD, nano sized distribution, laser deposition.
- Electro deposition: Types of electro chemical deposition, electro precipitation and non flow deposition.

2. Liquid phase production techniques:

- Liquid mixing method: The matrix is initially a classic cast liquid metal, and this is a simple and cheap method that is applied with the addition of admixture materials. This method enables to produce complex shaped items. Good results may not be able to be obtained if parameters such as temperature, pressure, contact time, solidification rate are not controlled. The low wetting ability of the ceramic phase with many metals is one of the most significant problems. The solution is directed to overcoming wetting in processes such as coating and pre-mixing or overcoming and removing surface energy with an external force. Thermal expansion compliance, shrinkage upon solidification and gas cavities are also important. Either the matrix alloy or the reinforcement agent needs

to be selected properly and mixing and casting must be performed under suitable conditions.

- Squeeze casting method: The liquid matrix material does not enable proper contact with reinforcement agents such as boron, carbide, graphite and silicon carbide. Wetting creates a cavity effect in this matrix and leads to significant strength losses. In squeeze casting fibres that have been heated and purified from gas with partial metal absorption are placed into a mould, external force is applied in order to increase interfacial surface binding strength by the effect of pressure. The force that is applied is continued until solidification is completed. This technique which has found a significant application field in metal matrix composite production enables to obtain products with smooth surfaces and low porosity. The system is continued to be developed in the automotive, defence and aviation sector. The disadvantage of the application is that the product per unit time is low. Deformation can be observed in the fibres and production difficulty increases with large sized parts and continuous production cannot be provided.
- Semi solid composite (Compocasting) casting method: In this application that is commonly used, particles, short fibre and non continuous fibre is fed to the matrix material having a semi solid phase temperature by means of a mixture. Following this, the mixture is pressed into heated moulds and is solidified. The most important disadvantages of this method are that the fibres can be damaged during mixing and lower homogeneity is achieved in complex mixtures.
- Mix (vortex) casting method: This is a method which depends on mixing of liquid metal with a mixer, and adding particle and short fibre admixtures during the mixing process. The mixing process is continued until the mixture is poured into the moulds. This method especially increases the wetting ability of ceramic surfaces. The tendency of porosity formation in the system is high and the reasons for this is that the liquid is in contact with the atmosphere due to the position of the mixer during mixing and the gas dissolved metal cannot be cleaned and the reinforcement agents are added without being heated.
- Reinforcement method by means of gas injection to the fluid: This is an application that is generally developed in order to add particles. The system generally is a nitrogen gas carrier. The matrix flows from the metal pot base and the particles are mixed by means of gas and at this instant homogenous mixture and small particles are formed.

- Plasma spraying (Osprey) method: The liquid metal is atomized with inert gas and as a result it is accumulated at the desired thickness on the mobile base. The system has been commercialized by Osprey Metals developed by Singer. Complex mixtures and special alloy matrices can be used with this system. The thickness of the piece is determined by controlling the accumulation at the base. If solidification is fast, the interfacial reaction of some oxides will be limited. This situation may limit the solubility rate and surface binding force will be weak.
- Liquid metal infiltration method: A matrix will be formed by infiltration of the liquid matrix material under pressure or vacuum to the structure that has been formed by fibre, whisker and particles. Moreover liquid pressure infiltration with nitrogen gas, and liquid pressure vacuum or non vacuum applications are also present.

The patent documents of the known state of the art numbered **US6547850B1**, **CN101020973A**, **CN101829777A**, **TR 2014 07923 B**, **CN101142045A** have been found to be similar to said invention.

- **US6547850B1**: This invention is related to a mixing technique which mixes particles into liquid or semi liquid matrix metal.
- **CN101020973A**: The invention is related to an apparatus which enables to produce metal matrix composites that have been reinforced with a multiple component phase.
- **CN101829777A**: A process for metal matrix composite materials that have been reinforced with nanoparticles has been described in this invention.
- **TR 2014 07923 B**: The invention describes a metal matrix composite casting method that has been developed in order to increase the abrasion resistance of steel alloys cast parts that are subjected to abrasion and impact.
- **CN101142045A**: The invention describes a metal matrix composite production method comprising processes such as hot-process isotactic compression of products related to the prior step and the cold press isotactic compression of powders.

The problems of the present systems have been defined below:

- High production costs: As the production methods are complicated this increases the product costs in unit basis.

- Some types of ceramic and graphite reinforcement materials display problems such as floating and mixing. This limits the production of improved quality materials.
- Reinforcement rate: This is an important production problem. In many methods viscosity and homogeneity problems are faced parallel with the increase of reinforcement rates.
- 5 - Strength loss due to surface wetting: Several reinforcement types are limited due to this reason. In most cases pre-processes are carried out (coating, high temperatures) in order to overcome this problem.
- Agglomeration: Agglomeration is formed when the reinforcement material is not distributed homogeneously inside a matrix and when the materials aggregate among themselves. The
- 10 problem is tried to be overcome by means of limiting reinforcement material amounts, particle size and form.
- Type of product: Most of the applications are carried out as continuous production (part). This also increases production costs in unit basis. Moreover it does not provide widespread usage as a semi-manufactured product.
- 15 - Interfacial reactions and solidification porosities: The expansion difference of the matrix material and the reinforcement material, the shrinkage following solidification and gas cavities lead to significant losses regarding the strength of the product.
- Continuous production: Continuous production in cast metal matrix composites is limited with product type and section. Generally part forming in a mould is used.
- 20 - Industrial usage: Many of the production methods have been developed according to requirements and they may not be used extensively and this limits production. However if the method has several controllable production parameters, this increases product variability.

Brief Description of the Invention and its Objections

- 25 The developed method aims to provide continuously squeezed metal matrix composite material production and to eliminate factors that reduce strength during production. The system enables continuous production, by means of an induction coil, a pot and a mould, around which thermal control is provided wherein an intermittent cylinder, is placed into the cylindrical mould, and is rotated around its axis, between phases of the cylinder liquid under atmosphere controlled
- 30 conditions is allowed to flow and solid matrix and reinforcement materials are added; pressure is applied with the radial opening and cool grinding base, the materials are squeezed and pushed with a rotational motion and the solidified section is released from the bottom of the mould.

The method that has been carried out enables the economical and continuous production of products such as, hollow cylinder, plate, non-hollow cylinders by benefiting from parameters like the temperature, pressure, rotational movement rate, and reinforcement types of liquid, semi-solid, solid (powder) products under controlled atmosphere conditions.

- 5** Advantages such as homogenous distribution, high ratio admixture addition, controlled solidification, smaller sized particle formation, strong and dense structure, less porosity, less flow and precipitation, prevention of floatation due to density, compatibility to cast and powder metal applications, reduction of production costs by providing continuous production, and mass production have been aimed to be reached by means of the developed system.

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Advantages of the developed system;

- It shall be possible to carry out continuous squeezed metal matrix composite (MMK) production.
- It is possible to increase quality by applying secondary processes.
- 15** - There are no dimensional limitations when adding reinforcement materials.
- It is possible carry out continuous squeezed metal matrix composite (MMK) production with magnesium matrix
- Cast MMK production with density problems such as graphite and ceramic can be performed easily and rapidly.
- 20** - Homogenous distribution and a dense but thin structure can be provided by controlling solidification rate and squeezing.
- The ratio of the reinforcement materials which is limited in other casting methods will not be a problem in this application.
- The viscosity problem observed in casting systems will not be a problem in this application.
- 25** - The solid-solid powder metal reinforced composites are continuously produced by induction sintering and axial squeezing.
- Gradual spreading is used which leads to a more homogenous structure.
- Complex mixtures such as liquid, fibre and powder are produced under control.
- 30** - Continuous production of plates, tubes and non hollow cylinders, having different diameters and wall thicknesses is enabled.

- Functional mixture structures can be continuously produced with different forms (cylinder, tube, plate) and diameters.
- The system shall prevent flotation by means of radial and vertical squeezing and shall provide homogenous distribution.
- 5 - The system provides controlled solidification and distribution.
- Pressurized squeeze controlled solidification of the system enables to overcome wetting problems.
- Large scale semi finished product production (plate, tube, non hollow cylinder) allows the product to be used in many sectors.
- 10 - The expansion difference of the matrix material and the reinforcement material, the shrinkage following solidification and gas cavities lead to significant losses regarding the strength of the product. The squeezing process of the system and the rotational movement, prevents these formations.
- As the method has several controllable production parameters, product variability is increased.
- 15 - The unit weight costs shall be reduced in comparison to present applications.
- There are no reinforcement ratio limitations and viscosity problems when this system is used. This also leads to increased composite quality values.
- Strength loss due to surface wetting is reduced by means of the system. High pressure and rotational movement is effective. This effect also prevents agglomeration and micro sedimentation.
- 20

DEFINITIONS OF THE FIGURES DESCRIBING THE INVENTION

- 25 **Fig. 1.** Continuous squeeze cast, metal matrix composite production system.
- Fig. 2.** Internal mould channel system for a pipe or non-hollow cylinder.

Definitions of the aspects/ sections/ parts forming the invention

- 30 1. Matrix liquid charge pot furnace

- 2. Furnace induction heating coil
- 3. Stationary internal mould
- 4. Metal flow channel
- 5. Rotational motion squeezer
- 5 6. Matrix liquid metal flow
- 7. Powder reinforcement admixture inlet
- 8. Strip reinforcement inlet
- 9. Inlet for gas with cooling pressure
- 10. Motor unit for rotational movement
- 10 11. Vertical press mechanism
- 12. Powder reinforcement flow and distribution system
- 13. Internal mould fixing beam
- 14. Stationary external mould with controlled induction temperature
- 15. Solidification area
- 15 16. Radial clamping jaw
- 17. Temperature controlled induction coil
- 18. Atmosphere controlled medium
- 19. External mould fixing beam
- 20. Products

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Detailed Description of the Invention

The invention is an (where the temperature of the flowing metal or squeezed material is controlled) composite production system comprising an induction system and a production method used in said system, wherein the distribution and spreading of flowing metal flowing out of a feeder pot, between two mould membranes with an axial rotation movement (matrix and reinforcement material) is carried out and where structural characteristics are also developed by squeezing with a vertically applied force.

The system is fed by charging the grooved channel which rotates at the axial centre, with liquid metal delivered from heat and flow controlled pots. The squeezing rotating cylinder can be fed

from a single point or from multiple points depending on its size. Physical layers are formed by delivering different metal phases from the second pot, to the metal flow channel (4).

Metal is delivered to the radial squeezer, in solid (powder sinter solid-liquid, and liquid form depending on rotation and cooling rate and is mixed and squeezed with reinforcement materials.

- 5 Squeezing does not only provide structural improvement (wetting, particle size reduction, degassing, reinforcement rate, preventing aggregation, and floatation etc.) but it also allows to solidify the product and enables it to be pushed and released out of the bottom of the mould and ensures continuous production.

- 10 Powder and fibre reinforcement materials besides matrix materials can be poured into the mould together or separately. Matrix or reinforcement materials can be fed from a single point or from a plurality of points depending on the size of the product. The amount of squeezing is controlled with dynamic brakes during loading and mould exit.

- 15 Temperature control is provided both in the pot and the mould by means of an induction coil. Pressurized nitrogen application controls the cooling of the mould and metal. The system performs continuous production by means of powder metal application in a mould with induction heating and sintering.

- 20 The system allows the flat metal and alloys to be obtained as a compressed structure. Especially metals which are difficult to produce such as magnesium can be mass produced in different forms (cylinder, tube, plate). Secondary metallurgical processes can be applied to the products.

The system also enables to efficiently produce polymer type materials. Here, the walls are covered with separating gels, the fibres are contacted by compression with resin, the gas cavities are removed and homogenous spreading is provided; solidification is provided by the heat of the mould during extraction.

- 25 In the system subject to the invention, in the atmospheric controlled environment (18), one of the single unit dual induction coil heating systems controls the temperature of the liquid in the charging pot while the other controls the heat in the production mould. According to the process, the opening at the rotation direction of the squeezer in the form of an intermittent cylinder, which applies vertical squeezing force and carries out an axial rotation motion between the two
30 telescopic and cylindrical stationary moulds containing liquid metal, has a wide angle and it

spreads and then squeezes the materials received from the charge channels to the base of the mould by a rotation motion. According to the process, the opening at the rotation direction of the squeezer in the form of an intermittent cylinder, which applies vertical squeezing force and carries out an axial rotation motion between the two telescopic and cylindrical stationary moulds containing liquid metal, has a wide angle and it spreads and then squeezes the materials received from the charge channels to the base of the mould by a rotation motion. The rotation speed determines the speed of solidification, the dendrite and particles that are solidified by squeezing, are homogenously distributed and besides this, shrinking due to wetting and solidification and gas cavities are reduced and a thinner and denser structure is formed. In MMK structures, the homogenous distribution of dense graphite and ceramic particles is carried out. The thickness formed as a result of the solidification following rotation motion, increases squeezing at the vertical direction and the section that is to be released from the mould is obtained. If the charge is continuous than the production of the product (20) from the mould is also continuous. The induction coil which is placed outside of the mould, controls the temperature of the squeezed material when desired and maintains the temperature at a semi solid or sintering temperature. The cooling is carried out during the discharge of the mould and from the inside of the mould. Cylindrical (hollow or non hollow) plate production having small diameters and lower thicknesses can be carried by means of the system.

The liquid metal that is charged to the induction heating pot under an atmosphere controlled medium (18), is poured in a controlled manner into the metal flow channel (4) having a radial opening. The liquid metal flows to the front section of the semi cylinder with radial edge, which rotates between the two telescopic cylindrical moulds intermittently. According to the aimed production; powder reinforcement or strip reinforcement is laid in front of the squeezer. Vertical pressure is applied to the material by means of a motor and roll bearing system. The rotation rate of the squeezer, the cooling gas and mould heating rate, the amount of reinforcement materials, the liquid, liquid-solid, solid-solid structure of the matrix, form the composition parameters. The solidified metal is released out of the mould and continuous production is performed.

The continuous squeeze cast composite production method used in said system comprises the following steps:

- Rotating the intermittent cylinder around its axis that has been placed inside two cylindrical moulds, wherein the thermal control around the pot and mould is provided by means of an induction coil,
- Liquid, liquid-solid, solid matrix and reinforcement materials are allowed to flow under controlled atmosphere conditions,
- Pressure is applied with the radial opening and cool grinding base, the materials are squeezed and pushed with a rotational motion,
- And the solidified section of the product is released from the bottom of the mould, thereby continuous production is performed.

Improved quality production which is domestic and more economic will be enabled in fields where present metal matrix composite applications are used such as engine cylinders, special cylinders of the defence industry products, armour materials, sole plates that have high thermal conductivity and heat dissipater properties, electronic cooling elements besides semi finished products with high strength properties which will be utilized by the manufacturers by means of the technique that shall be applied.

Said MMK system is suitable especially for semi finished products. These products can also be industrialized and can be utilized extensively such as rolling and extrusion methods used nowadays in iron-steel production. Moreover this system can also be used in specific productions directed to reach a certain aim.

Applicable fields:

- Automobile chassis, transfer shafts, brake discs, lightweight applications with application (Mg, Al) matrix which provide energy saving,
- Materials for the defence industry, such as armour and missiles etc and materials with high or low strength,
- Ship building industry,
- Semi finished production (machining, laser and press shaping)
- Solid-solid powder metal continuous production and
- Magnesium plate production.

CLAIMS

1. A continuous squeeze cast composite production method characterized in that it comprises the steps of;
 - 5 - Rotating the intermittent cylinder around its axis that has been placed inside two cylindrical moulds, wherein the thermal control around the pot and mould is provided by means of an induction coil,
 - Liquid, liquid-solid, solid matrix and reinforcement materials are allowed to flow under controlled atmosphere conditions,
 - 10 - Pressure is applied with the radial opening and cool grinding base, the materials are squeezed and pushed with a rotational motion,
 - And the solidified section of the product is released from the bottom of the mould, thereby continuous production is performed.
- 15 2. A continuous squeeze casting composite production system wherein the production method according to claim 1 is applied.
3. A production system according to claim 2, characterized in that the system has a structure that is suitable to carry out polymer and polymer-metal reinforced composite production.
- 20 4. A production system according to claim 2, characterized in that, it has a structure which enables continuous production of plates, tubes and non hollow cylinders, having different diameters and wall thicknesses.
5. A production system according to claim 2, characterized in that it is designed to be able to provide seamless and large scale metal matrix composite productions by means of
- 25 being fed from multiple points.
6. A production system according to claim 2, characterized in that the solid powder matrix and the reinforcement mixture can be shaped by sintering.
7. A composite product that has been produced by means of a continuous composite production method according to claim 1.
- 30 8. A composite material according to claim 7, characterized in that it is a squeezed metal composite.

9. A composite material according to claim 7, characterized in that it is a multilayered composite.

10. A composite material according to claim 7, characterized in that the product is a smaller product whose semi solid form dendrites in the matrix have been rotationally squeezed.

5 11. A composite material according to claim 7, characterized in that it is a continuous composite comprising solid-solid powder metal admixture.

10 12. A production system according to claim 2, characterized in that, it comprises a matrix liquid charged melting pot, a furnace induction heating coil, a stationary inner mould, a metal flow channel, rotating squeezer, matrix liquid metal flow, powder reinforcement material inlet, strip reinforcement inlet, pressurized cool gas inlet, rotating motion motor unit, vertical pressure mechanism, powder reinforcement material flow and distribution system, inner mould fixing beam, temperature controlled stationary external mould, solidification area, radial clamp jaw, temperature control induction coil, controlled atmosphere medium, and an external mould fixing beam.

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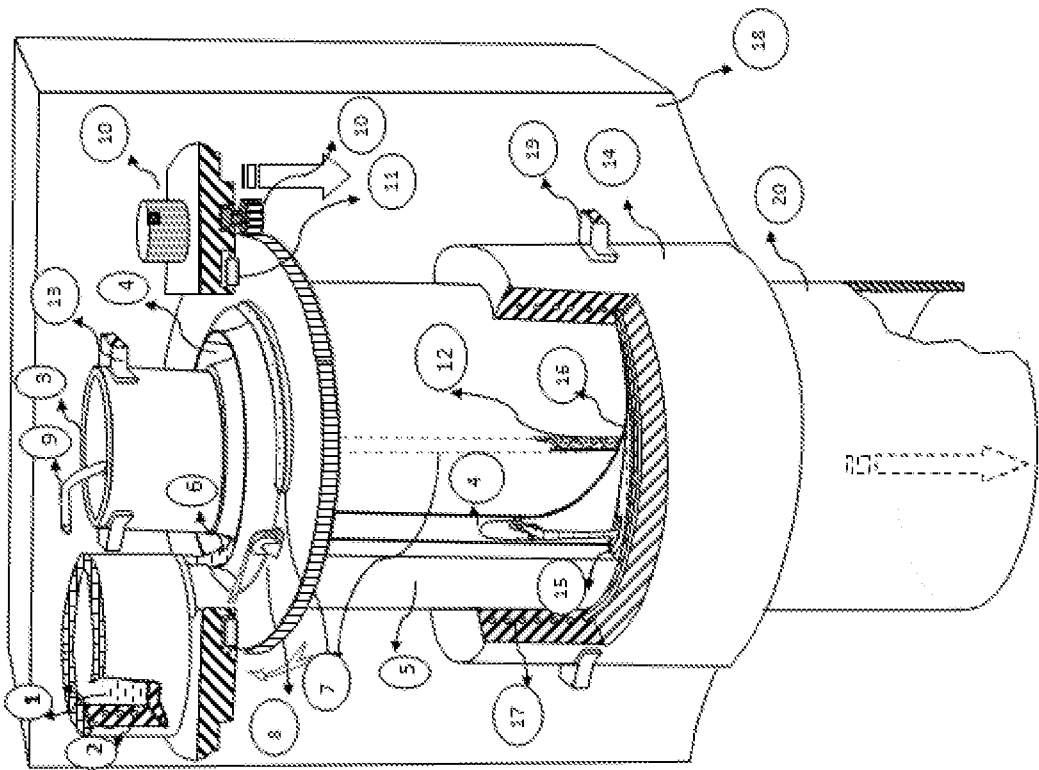


Figure 1

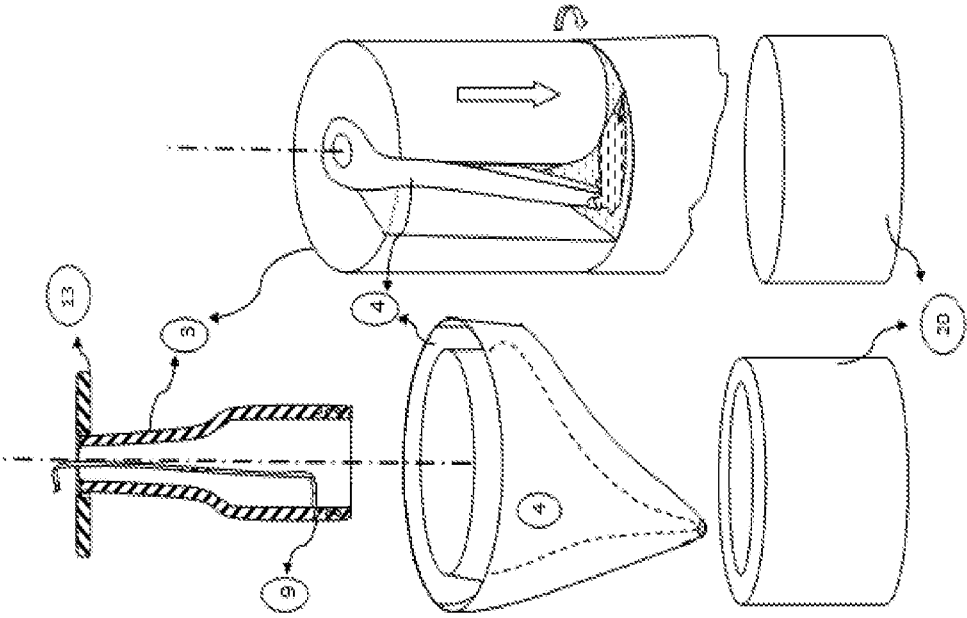


Figure 2