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(54) **METHOD AND APPARATUS FOR MANUFACTURING A HYDROGEN TANK WALL, AND WALL COMPONENT FOR SUCH TANK WALL**

(57) For improving leak tightness of vehicle hydrogen tanks, the invention provides a manufacturing method for manufacturing a hydrogen tank wall, comprising the steps of:
a) providing at least one wall component (14) made from fibre reinforced composite material,
b) coating the at least one wall component (14) with a metallic material by a cold spray process, and
c) using the at least one wall component (14) to form the hydrogen tank wall.

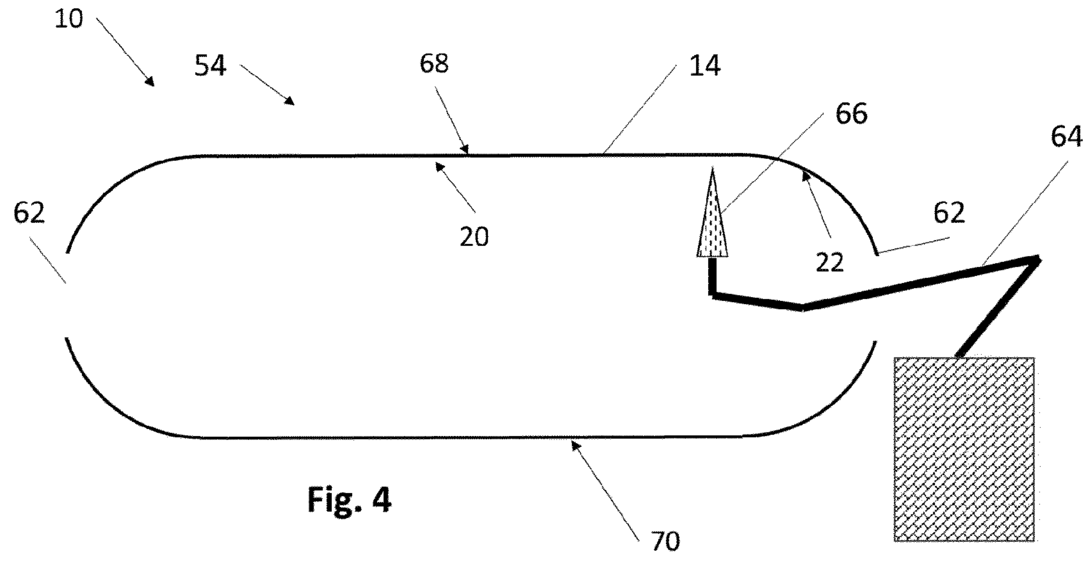

Fig. 4

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Description

[0001] The invention relates to a manufacturing method for manufacturing a hydrogen tank wall, especially a cryogenic tank wall. Further, the invention relates to a hydrogen tank, especially a cryogenic tank, for a vehicle, especially an aircraft, comprising a tank wall component having a substrate of fibre reinforced composite material. Still further, the invention relates to a manufacturing apparatus for manufacturing a hydrogen tank, especially a cryogenic tank.

[0002] For the technical background of the invention, reference is made to the following citations:

[1] US 2015/0 336 680 A1
[2] EP 3 498 664 B1
[3] FR 3 048 980 A1
[4] EP 2 027 305 B1
[5] EP 3 401 419 B1
[6] US 11 167 864 B2
[7] Cold spraying - Wikipedia, downloaded on 13.05.2022 from https://en.wikipedia.org/wiki/Cold_spraying
[8] Thermal Expansion - Wikipedia, downloaded on 25.05.2022 from https://en.wikipedia.org/wiki/Thermal_expansion

[0003] Cryogenic storage tanks may be used for storing liquid hydrogen, for example, for use as a fuel for driving a vehicle. The vehicle may be a motor vehicle such as a car, lorry or train or may be an aircraft. Citations [1] and [2] disclose a tank for the cryogenic storage of hydrogen and an aircraft with a tank installed therein. Liquid hydrogen stored within the tank is used as a fuel for the aircraft engine in place of carbon-based fuels such as kerosene. The cryogenic storage tank is typically substantially cylindrical and includes openings for allowing the tank to be filled with hydrogen as well as to supply the stored liquid hydrogen to the engine.

[0004] Lightweight energy storage is a key topic for next generation aircrafts. Storage systems with high energy density are one of the key challenges for future electrical propulsion-based systems. Different energy storage systems are available today, whereas pressurized (~700 bar) or cryogenic Hydrogen ($14 K < T < 21 K$) paired with fuel cells or direct burn are interesting solutions for next flight vehicles. Hydrogen ($H2$) is the molecule with lowest density and smallest diameter in nature, which is why the storage in tanks is very complex and hardly achievable without leakage over longer durations.

[0005] Hydrogen offers high energy densities, whereas the storage technique (cryogenic, compressed, solid state/absorbed) is a key issue. Hydrogen can be compressed and/or cooled down to cryogenic temperatures to increase the volumetric and gravimetric energy density. Usually, complex tank systems are needed with individual requirements to the materials, design and working principle e.g., regarding operational safety.

[0006] Compressed and cryogenic hydrogen are the techniques of choice for today's vehicles, like cars or airplanes. Cryogenic tanks can achieve the lowest added weight wherein, with the present known technologies, about 0.2 kg - 0.5 kg tank weight is needed per kg stored H2. Conventional tanks work with applied inner pressure to avoid gas ingress from outside. As tank material typically metals, metal alloys and composites are in use. Full composite tanks can be challenging because of the long in-service life of civil aircraft. Hydrogen leakage may also be an issue.

[0007] An object of the invention is to improve leak tightness of hydrogen tanks made of composite material.

[0008] The object is achieved by the subject-matter of the independent claims.

[0009] Preferred embodiments are subject-matters of the dependent claims.

[0010] The invention provides a manufacturing method for manufacturing a hydrogen tank wall, especially a cryogenic tank wall for a tank for storing liquid hydrogen, comprising the steps of:

a) providing at least one wall component made from fibre reinforced composite material,
b) coating the at least one wall component with a metallic material by a cold spray process, and
c) using the at least one wall component to form the hydrogen tank wall.

[0011] Preferably, step b) comprises: cold spraying a metal material having a thermal expansion coefficient that is lower than a thermal expansion component of the reinforced composite material onto at least one surface of the wall component. As a result, the cold spray coating applied to at least one surface of the wall component substrate has a lower CTE as the substrate which is made from composite material.

[0012] Preferably, step a) comprises
a1) providing at least one wall component in a tube shape.

[0013] Preferably, step a) comprises
a2) providing at least one wall component with the shape of a cap.

[0014] Preferably, step a) comprises

a3) winding a prepreg on a winder in order to form the at least one wall component.

[0015] Preferably, step a) comprises

a4) stacking several prepregs with different fibre orientation in order to form the at least one wall component.

[0016] Preferably, step a) comprises

a5) combining layers of composite material with different fibre orientations to form the at least one wall component.

[0017] Preferably, step a) comprises

a6) providing the at least one wall component having a linear thermal expansion coefficient CTEc with $2*10^{-6} K^{-1} \leq CTEc \leq 34*10^{-6} K^{-1}$, preferably $5*10^{-6} K^{-1} \leq CTEc \leq 15*10^{-6} K^{-1}$, most preferred $9*10^{-6} K^{-1} \leq CTEc \leq 10*10^{-6} K^{-1}$.

[0018] Preferably, step a) comprises

a7) providing the at least one wall component made from a CFRP composite material.

[0019] Preferably, step b) comprises:

b1) conducting the cold spray process with a powder from metallic material having a linear thermal expansion coefficient CTE_M with

$-30*10^{-6} K^{-1} \leq CTE_M \leq 9*10^{-6} K^{-1}$.

[0020] Preferably, step b) comprises:

b2) using one or several metallic materials from the group consisting of iron alloy, nickel alloy, FeNi36(Invar), FeNi36(extrapure), Fe-29Ni-17CO, wolfram, titan, and negative CTE alloy.

[0021] Preferably, step b) comprises:

b3) using a carrier gas from the group consisting of air, inert gas, noble gas, nitrogen, and helium.

[0022] Preferably, step b) comprises:

b4) conducting the cold spray process with a gas pressure p with $40 \text{ bar} \leq p \leq 70 \text{ bar}$.

[0023] Preferably, step b) comprises:

b5) conducting the cold spray process with a gas temperature T with $750°C \leq T \leq 1000°C$.

[0024] Preferably, step b) comprises:

b6) conducting the cold spray process with a powder having particle diameters pd with $25 \mu m \leq pd \leq 60 \mu m$.

[0025] Preferably, step b) comprises:

b7) applying a bonding layer on the composite material surface to be coated and applying the coating by the cold spray process over the bonding layer.

[0026] Preferably, step b) comprises:

b8) coating an inner surface of the wall component which forms, in use of the wall component in the cryogenic tank, an inner surface area of the tank.

[0027] Preferably, step b) comprises:

b9) conducting the cold spray process with a spray head arranged on a robotic arm.

[0028] According to another aspect, the invention provides a hydrogen tank for a vehicle, especially an aircraft, preferably a cryogen tank for storing liquified hydrogen, the hydrogen tank comprising a tank wall component having a substrate of fibre reinforced composite material coated with a cold sprayed metallic material layer.

[0029] Preferably, the metallic material layer has a lower thermal expansion coefficient as the fibre-reinforced composite material layer.

[0030] Preferably, the fibre-reinforced composite material substrate has a linear thermal expansion coefficient CTEc with $2*10^{-6} K^{-1} \leq CTE_C \leq 34*10^{-6} K^{-1}$, more preferably $5*10^{-6} K^{-1} \leq CTEc \leq 15*10^{-6} K^{-1}$, most preferred $9*10^{-6} K^{-1} \leq CTEc \leq 10*10^{-6} K^{-1}$ and/or wherein the metallic material of the coating has a linear thermal expansion coefficient CTE_M with $-30*10^{-6} K^{-1} \leq CTE_M \leq 9*10^{-6} K^{-1}$

[0031] Preferably, the wall component has an inner surface defining a portion of the inner tank surface coated with the cold sprayed metallic material.

[0032] Preferably, the hydrogen tank is achieved by the manufacturing method according to any of the aforementioned embodiments.

[0033] According to another aspect, the invention provides a vehicle, especially an aircraft, comprising a hydrogen tank according to any of the aforementioned embodiments.

[0034] According to another aspect, the invention provides a manufacturing apparatus for manufacturing a hydrogen tank, especially a cryogen tank for storing liquid hydrogen (LH2) comprising

a wall component manufacturing unit for manufacturing a wall component made from fibre reinforced composite material,

a cold spray coating unit configured to apply a coating of a metallic material onto at least one surface of the wall component by conducting a cold spray process, and

a tank assembly unit configured to assemble the at least one wall component coated by cold spraying together with further components to form the hydrogen tank.

[0035] Preferred embodiments of the invention relate to a cold spray inner coating for H2-tanks. Preferably, the proposed coating relates to an application for a tank containing cryogenic fluids (H2). Therefore, an application within hydrogen powered aircrafts is possible.

[0036] Tank structures for cryogenic fluids like liquid H2 are often manufactured from metallic material. For an aeronautical application these tanks are too heavy. The use of composite material for cryogenic tanks results in much lighter structures. But due to the different thermal expansion coefficients of fibre and matrix material microcracks in the matrix material can occur. These cracks will result in an increased loss rate of liquid hydrogen.

[0037] The Cold Spray process enables the coating of composite parts with metallic material. This will create a crack resistant coating.

[0038] As defined in [7], cold spraying (CS) - also called gas dynamic cold spraying - is a coating deposition method in which solid powders (1 to 50 micrometers in diameter) are accelerated in a supersonic gas jet to velocities up to ca. 1200 m/s, wherein, during impact with the substrate, particles undergo plastic deformation and adhere to the surface.

[0039] To achieve a uniform thickness the spraying nozzle is scanned along the substrate. Metals, polymers, ceramics, composite materials and nanocrystalline powders can be deposited using cold spraying. The kinetic energy of the particles, supplied by the expansion of the gas, is converted to plastic deformation energy during bonding. Unlike thermal spraying techniques, e.g., plasma spraying, arc spraying, flame spraying, or high velocity oxygen fuel (HVOF), the powders are not melted during the spraying process. For further details to cold spraying reference is made to citations [3] to [7]. As indicated and explained in [5] and [6], it is also possible to coat fibre reinforced composite materials such as CFRP (carbon fibre reinforced plastic) with a metallic material by using cold spraying.

[0040] As can be noted therefrom, cold spray coatings differ from coatings made with other coating deposition processes.

[0041] By the cold spray process, the powder particles undergo a plastic deformation. The particles are cold-welded to the substrate being coated. The metallic surface achieved by the cold spraying is under compressive stress. Cracks in the composite tank wall component are closed and pressed shut by this compression. Hence, the leak tightness is improved.

[0042] Most preferred, the coating is applied onto at least one surface, preferably the inner surface or inside surface of a tank wall component for a cryogenic H2 tank.

[0043] Using a metallic material with a lower thermal expansion coefficient than the composite material for coating, an inner surface of a tank structure can be created that will remain in a compressed state when exposed to cryogenic temperatures due to the larger shrinkage of the composite. Due to this, the creation of microcracks in the coating is not possible. This will reduce the leakage rate of liquid hydrogen (H2).

[0044] During the Cold Spray process a metal powder is blasted with supersonic velocity onto a target substrate. This is also applicable for fibre composite substrates. With this process a metallic coating can be applied onto the inner surface of a composite tank. Using preferably metallic material with a low thermal expansion coefficient (e.g. Invar (FeNi)) in combination with a composite material of a higher CTE (Coefficient of Thermal Expansion, see [8]) than the metal, a hybrid tank wall can be created. When exposed to cryogenic temperatures (liquid H2) the composite wall will contract more than the metallic coating. Therefore, the metallic coating will stay in a compressed state. This compressed state of the metallic coating will prevent microcracks. Due to this the leakage rate of H2 can be reduced.

[0045] Preferably, the tank is formed as a tube. For example, the tank has essentially a cylindrical shape. A wall component for such tank can be manufactured by winding a composite material, especially a prepreg, more preferred a CFRP prepreg onto a winding machine (shortly referred to as winder). Thus, a tubelike cylindrical structure with open ends is achieved. Through the open end, a robotic arm with a cold spray head, e.g., such as indicated in [7], can reach the inner surface and apply the cold spray coating onto the inner surface. It is also possible to manufacture several components, e.g., half-shells or two halves of the tank, for example two half spheres or two halves of a cylinder, to coat the inner side thereof and to then assemble these components to arrive at the tank module.

[0046] Preferably, the wall thickness of the composite tank wall component (=target substrate) is at least 4 mm or more. As known from [5] and [6], a bonding layer may be applied first in order to enhance the coating. However, with lower gas pressure, the cold spray coating also works without a bonding layer. For further advantages of the cold spraying, reference is made to [7].

[0047] Preferred embodiments of the invention are explained in more detail below referring to the accompanying drawings in which:

Fig. 1 shows a perspective schematic view of an aircraft as an example for a vehicle equipped with a hydrogen tank, especially a cryogenic tank for storing liquid hydrogen (LH2);

Fig. 2 shows a schematic block diagram of a manufacturing apparatus for manufacturing the hydrogen tank;

Fig. 3 shows a schematic perspective view of an example for a wall component manufacturing unit;

Fig. 4 shows a schematic view of a cold spray unit together with a wall component to be coated by cold spraying;

Fig. 5 a schematic view of a further embodiment of wall components for the hydrogen tank;

Fig. 6 shows a schematic view of the cold spray unit conducting a cold spray coating of the wall component according to an embodiment of a manufacturing method for the hydrogen tank; and

Fig. 7 shows at least a part of an embodiment of a tank assembly unit during assembly of tank components.

[0048] Fig. 1 shows an aircraft, especially an airplane 44 as an example for a vehicle 12 in which a hydrogen tank 10 is used. The airplane 44 has a propulsion system 46 with turbines 42 as engines 26. The turbines 42 are configured to burn hydrogen supplied from the hydrogen tank 10. Further, the airplane 44 may be equipped with fuel cells (not shown), wherein hydrogen is supplied to the fuel cells from the hydrogen tank 10.

[0049] The hydrogen tank 10 has, e.g., a cylindrical shape. The hydrogen tank 10 is configured as a cryogenic tank for storing liquid hydrogen (LH2) at cryogenic temperatures. At least one wall component 14 of the tank, such as for example the middle cylindrical part 16 or an end cap 18 is made of fibre reinforced composite material. The inner surface 20 of the wall component 14 is coated with a cold spray coating 22 of metallic material. Here, the inner surface 20 is the surface having contact with the LH2.

[0050] Fig. 2 shows a schematic block diagram of a manufacturing apparatus 50 for manufacturing the hydrogen tank 10. The manufacturing apparatus 50 comprises a wall component manufacturing unit 52, a cold spray coating unit 54 and a tank assembly unit 56. The wall component manufacturing unit 52 is configured for manufacturing the wall component 14 made from fibre reinforced composite material. The cold spray coating unit 54 is configured to apply the coating of metallic material onto at least one surface, especially the inner surface 20, of the wall component 14 by conducting a cold spray process. The tank assembly unit 56 is configured to assemble the at least one wall component 14 coated by cold spraying together with further components to form the hydrogen tank 10.

[0051] Fig. 3 shows a schematic perspective view of an example for the wall component manufacturing unit 52. The wall component manufacturing unit 52 comprises a winder 58 onto which several layers of CFRP prepregs 60 can be wound in order to achieve the wall component 14.

[0052] Preferred carbon fibre prepreg materials (UD prepregs, i.e. prepregs with unidirectional fibres) and their CTEs are indicated in the following table 1:

Table 1: preferred CFRP prepreg materials for production of the wall component 14

Name	CTE in fibre direction	CTE transversal to fibre direction
IMA/M21E	$0.15*10^{-6}$ K^{-1}	$28.7*10^{-6}$ K^{-1}
HTS/913	$3.4*10^{-6}$ K^{-1}	$34*10^{-6}$ K^{-1}
HTA/EH25	$3.4*10^{-6}$ K^{-1}	$34*10^{-6}$ K^{-1}
IM7/M20	$3.4*10^{-6}$ K^{-1}	$34*10^{-6}$ K^{-1}
T800/M21	$2.3*10^{-6}$ K^{-1}	$34*10^{-6}$ K^{-1}

[0053] By combining several prepreg layers with different fibre orientation the final wall component 14 has typically a linear CTEc in the area up to $10*10^{-6}$ K^{-1}. For example, a wall component 14 is achieved having a CTEc with $2*10^{-6}$ K^{-1} $\leq$ CTEc $\leq$ $34*10^{-6}$ K^{-1}, preferably $5*10^{-6}$ K^{-1} $\leq CTE_C \leq$ $15*10^{-6}$ K^{-1}, most preferred $9*10^{-6}$ K^{-1} $\leq$ CTEc $\leq$ $10*10^{-6}$ K^{-1}. By stacking several prepreg 60 layers, the wall component 14 is preferably manufactured with a wall thickness of at least 4 mm or more.

[0054] Fig. 4 shows a schematic view of an embodiment of the cold spray unit 54 together with the wall component 14 to be coated by cold spraying. The wall component 14 is manufactured and provided as an essentially cylindrical wall element with polar openings 62. The cold spray unit 54 comprises a robotic arm 64 adapted and configured to pass through the polar opening 64 and equipped with a cold spray head 66 as generally known, for example from [3] to [7]. The cold spray unit 54 is configured to coat the inner surface of the hydrogen tank 10 through the polar openings 62 by a cold spray process with a metallic material.

[0055] The Cold Spray process comprises the following steps:

- Mixing a metallic powder with gas (Air, inert gas, N2, noble gas or He)
- Powder particles are accelerated by the jet of gas up to supersonic speed

- Powder particles remain in solid state during spraying
- Cold Spray rely only on plastic deformation to build up coatings

[0056] In a preferred embodiment, the CTE_M of the metallic material is lower than the CTEc of the wall component. For the metallic coating, metals or metal alloys are preferred having an $CTE_M < 9*10^{-6}\ K^{-1}$. Examples for CTE of different materials are indicated in [8]. Preferably, powder from metallic material is used which has a linear thermal expansion coefficient CTE_M with $-30*10^{-6}\ K^{-1} \leq CTE_M \leq 9*10^{-6}\ K^{-1}$. Preferred materials are indicated in the following table 2:

Name	CTE_M
FeNi36 (Invar)	$1.2*10^{-6}\ K^{-1}$
FeNi36 extrapure	$0.65*10^{-6}\ K^{-1}$
Fe-29Ni-17Co	$5.5*10^{-6}\ K^{-1}$
Wolfram	$4.5*10^{-6}\ K^{-1}$
Titan	$8.5*10^{-6}\ K^{-1}$
ALLVAR®	negative CTE, $-20*10^{-6}\ K^{-1}$ to $-10*10^{-6}\ K^{-1}$, also $-30*10^{-6}\ K^{-1}$ possible, see [8]

[0057] Allvar® is a metallic alloy that is commercial available and has a negative CTE_M.

[0058] Preferably, the cold spray process is conducted with the following parameters:

Carrier gas: He or N2 preferred
Gas pressure p: 40 bar to 70 bar
Gas temperature T: 750°C to 1100°C
Particle size: 25 μm to 60 μm.

[0059] Using the wall component 14 being coated by cold spraying as described above, the hydrogen tank 10 is assembled in the tank assembly unit 56 in a conventional manner by mounting further tank or system components to the wall component 14. In the embodiment of Fig. 4, the wall component 14 is configured as a basic structure 68 and as a structural support 70 of the tank 10. In an assembling step, the polar openings 62 can be closed by end caps 18 (not shown in Fig. 4). Further hydrogen system components such as pipes, ducts, ventils, thermal isolation, structural support components and so on (not shown) are mounted.

[0060] Referring to Figs. 5 to 7, an alternative embodiment for a manufacturing method for the hydrogen tank 10 is described in the following.

[0061] Fig. 5 shows a schematic view of a first and second wall component 14 for the hydrogen tank 10 according to another embodiment. Fig. 6 shows a schematic view of another embodiment of the cold spray unit 54 conducting a cold spray coating of the wall component 14 according to the further embodiment of the manufacturing method for the hydrogen tank 10. Fig. 7 shows at least a part of an embodiment of the tank assembly unit 58 during assembly of tank components.

[0062] As shown in Fig. 5, several wall components 14 form together the basic structure 68 of the hydrogen tank 10. In the embodiment shown, a first and second wall component 14 form two halves of the basic structure 68. According to one embodiment, the basic structure 68 can be manufactured in the wall component manufacturing unit 52 as one part - essentially as described above with reference to Figs. 3 and 4 -and can then be divided into several parts, for example two halves, as indicated with a dividing line 72. According to another embodiment, the several parts, for example the two halves, which each constitute a wall component 14 of the hydrogen tank 10, can be manufactured separately and can be provided separately to the cold spray unit 54 which is shown in Fig. 6.

[0063] As shown in Fig. 6, the cold spray coating can be applied through the large opening 74 of the first and second wall component 14, respectively (the large opining 74 is defined at the dividing line 72 in Fig. 5). Hence, the robotic arm 64 does not need to be configured to reach through the small polar opening 62 as in the embodiment of Fig. 4.

[0064] As shown in Fig. 7, the coated wall components 14 can then be assembled (with their large openings 74 put together) in the tank assembly unit 58. In the embodiment shown, the first and second halve of the basic structure 68 are mounted together and wrapped with additional layers of the CFRP prepreg 60 until a predefined wall thickness of the basic structure 68 of the hydrogen tank 10 is achieved.

[0065] Hence, a manufacturing method for manufacturing a hydrogen tank wall has been described, comprising the steps of:

a) providing at least one wall component 14 made from fibre reinforced composite material,

b) coating the at least one wall component 14 with a metallic material by a cold spray process, and
c) using the at least one wall component 14 to form the hydrogen tank wall.

Reference sign list:

[0066]

10	hydrogen tank
12	vehicle
14	wall component
16	cylindrical part
18	end cap
20	inner surface
22	cold spray coating
26	engine
42	turbine
44	airplane
46	propulsion system
50	manufacturing apparatus
52	wall component manufacturing unit
54	cold spray unit
56	tank assembly unit
58	winder
60	prepreg
62	polar opening
64	robotic arm
66	cold spray head
68	basic structure
70	structural support
72	dividing line
74	large opining

Claims

1. Manufacturing method for manufacturing a hydrogen tank wall, comprising the steps of:

a) providing at least one wall component (14) made from fibre reinforced composite material,
b) coating the at least one wall component (14) with a metallic material by a cold spray process, and
c) using the at least one wall component (14) to form the hydrogen tank wall.

2. Manufacturing method according to claim 1, **characterized in that** step b) comprises: cold spraying the metallic material having a thermal expansion coefficient that is lower than a thermal expansion component of the reinforced composite material onto at least one surface (20) of the wall component (14).

3. Manufacturing method according to any one of the preceding claims, **characterized in that** step a) comprises at least one or several of the steps:

a1) providing at least one wall component (14) in a tube shape,
a2) providing at least one wall component (14) with the shape of a cap,
a3) winding a prepreg (60) on a winder (58) in order to form the at least one wall component (14),
a4) stacking several prepregs (60) with different fibre orientation in order to form the at least one wall component (14),
a5) combining layers of composite material with different fibre orientations to form the at least one wall component (14),
a6) providing the at least one wall component (14) having a linear thermal expansion coefficient CTEc with $2*10^{-6}\ K^{-1} \leq CTEc \leq 34*10^{-6}\ K^{-1}$, preferably $5*10^{-6}\ K^{-1} \leq CTEc \leq 15*10^{-6}\ K^{-1}$, most preferred $9*10^{-6}\ K^{-1} \leq CTEc \leq 10*10^{-6}\ K^{-1}$,

a7) providing the at least one wall component (14) from a CFRP composite material.

4. Manufacturing method according to any of the preceding claims, **characterized in that** step b) comprises at least one or several of the steps:

b1) conducting the cold spray process with a powder from metallic material having a linear thermal expansion coefficient CTE_M with
$-30*10^{-6}\ K^{-1} \leq CTE_M \leq 9*10^{-6}\ K^{-1}$
b2) using one or several metallic materials from the group consisting of iron alloy, nickel alloy, FeNi36(Invar), FeNi36(extrapure), Fe-29Ni-17CO, wolfram, titan, and negative CTE alloy,
b3) using a carrier gas from the group consisting of air, inert gas, noble gas, nitrogen, and helium;
b4) conducting the cold spray process with a gas pressure p with 40 bar $\leq p \leq$ 70 bar,
b5) conducting the cold spray process with a gas temperature T with 750°C $\leq T \leq$ 1000°C;
b6) conducting the cold spray process with a powder having particle diameters pd with 25 μm $\leq pd \leq$ 60 μm;
b7) applying a bonding layer on the composite material surface to be coated and applying the coating by the cold spray process over the bonding layer;
b8) coating an inner surface (20) of the wall component (14) which forms, in use of the wall component in the hydrogen tank (10), an inner surface area of the tank (10);
b9) conducting the cold spray process with a cold spray head (66) arranged on a robotic arm (54).

5. Hydrogen tank (10) for a vehicle (12), especially an aircraft, comprising a tank wall component (14) having a substrate of fibre reinforced composite material coated with a cold sprayed metallic material layer.

6. Hydrogen tank (10) according to claim 5, wherein the metallic material layer has a lower thermal expansion coefficient as the fibre-reinforced composite material substrate.

7. Hydrogen tank (10) according to claim 5 or 6, wherein the fibre-reinforced composite material substrate has a linear thermal expansion coefficient CTEc with $2*10^{-6}\ K^{-1} \leq CTEc \leq 34*10^{-6}\ K^{-1}$, preferably $5*10^{-6}\ K^{-1} \leq CTEc \leq 15*10^{-6}\ K^{-1}$, most preferred $9*10^{-6}\ K^{-1} \leq CTEc \leq 10*10^{-6}\ K^{-1}$ and/or wherein the metallic material of the coating has a linear thermal expansion coefficient CTE_M with
$-30*10^{-6}\ K^{-1} \leq CTE_M \leq 9*10^{-6}\ K^{-1}$

8. Hydrogen tank according to any of the claims 5 to 7, wherein the wall component (14) has an inner surface (20) defining a portion of the inner tank surface coated with the cold sprayed metallic material.

9. Vehicle (12), especially aircraft, comprising a hydrogen tank (10) according to any of the claims 5 to 9.

10. Manufacturing apparatus (50) for manufacturing a hydrogen tank (10), comprising

a wall component manufacturing unit (52) for manufacturing a wall component (14) made from fibre reinforced composite material,
a cold spray coating unit (54) configured to apply a coating of a metallic material onto at least one surface (20) of the wall component (14) by conducting a cold spray process, and
a tank assembly unit (56) configured to assemble the at least one wall component (14) coated by cold spraying together with further components to form the hydrogen tank (10).

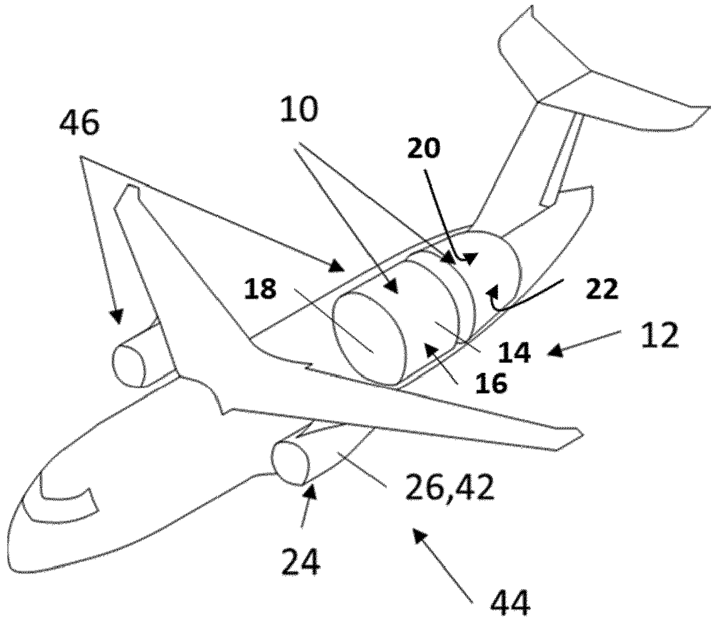


Fig. 1

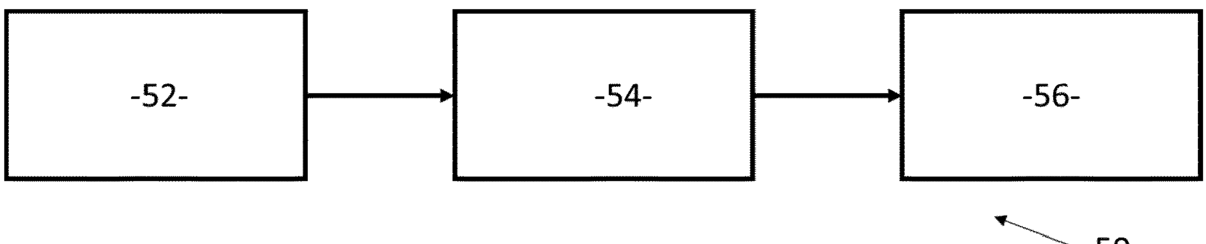


Fig. 2

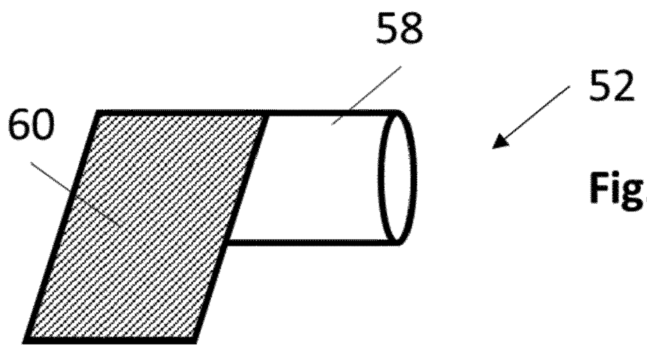


Fig. 3

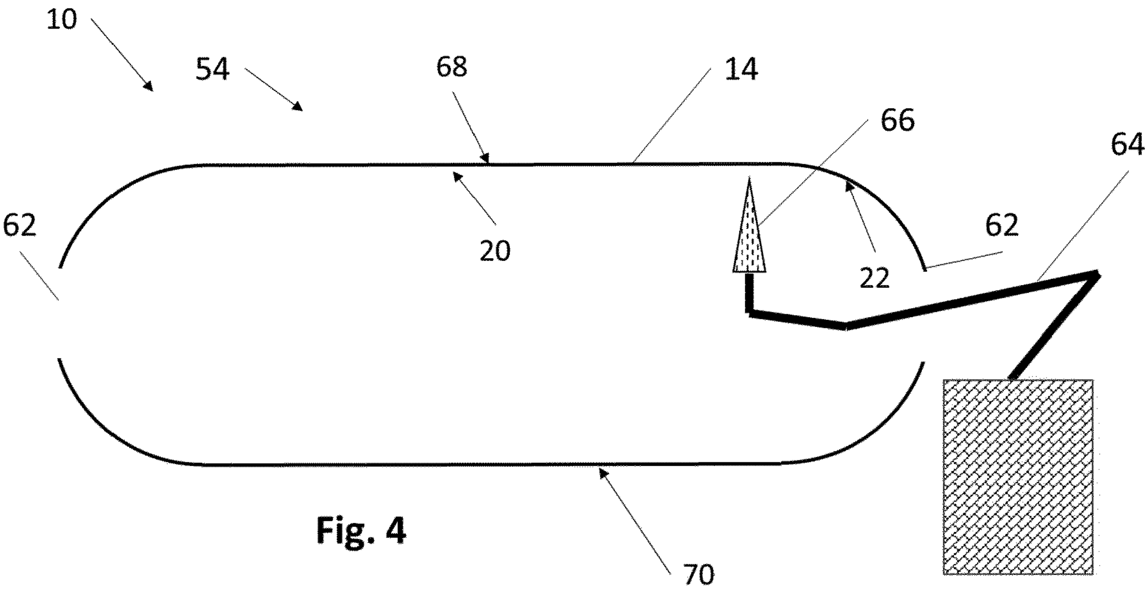


Fig. 4

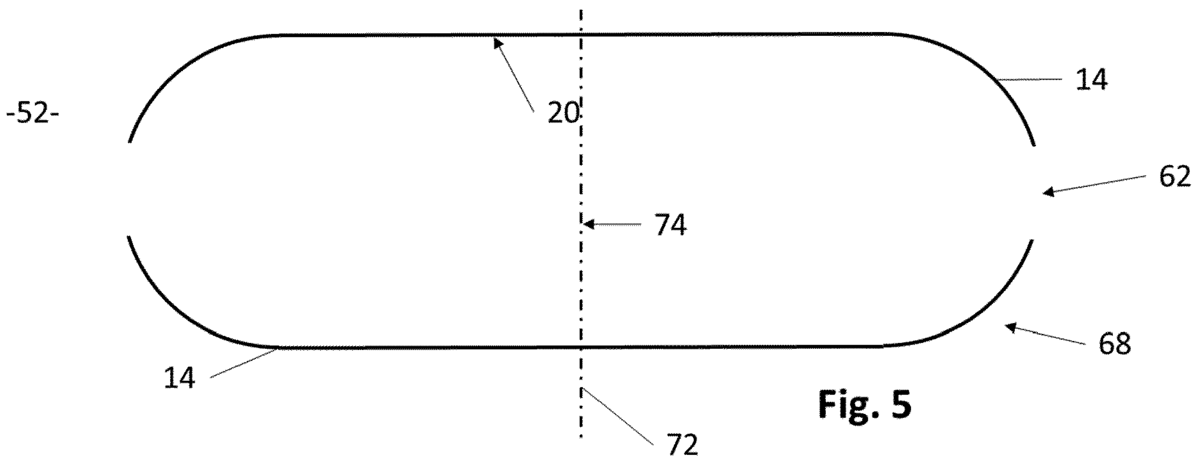
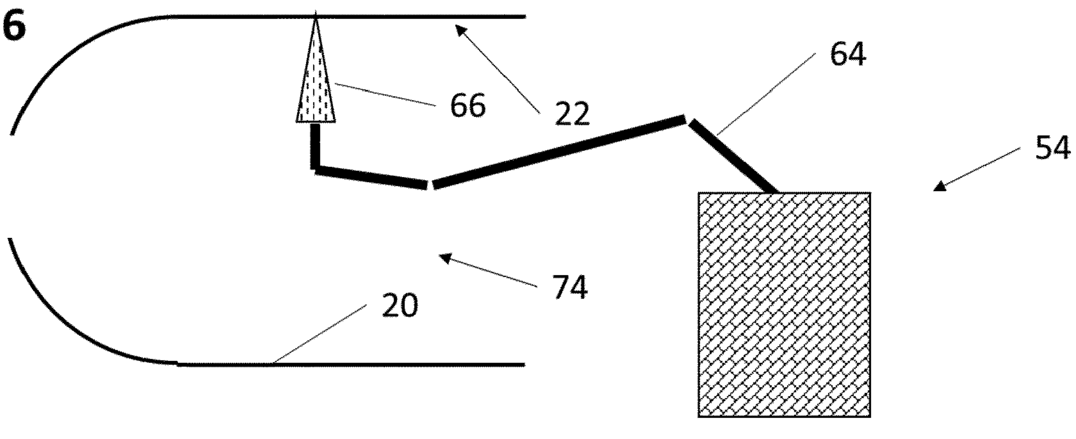


Fig. 5

Fig. 6



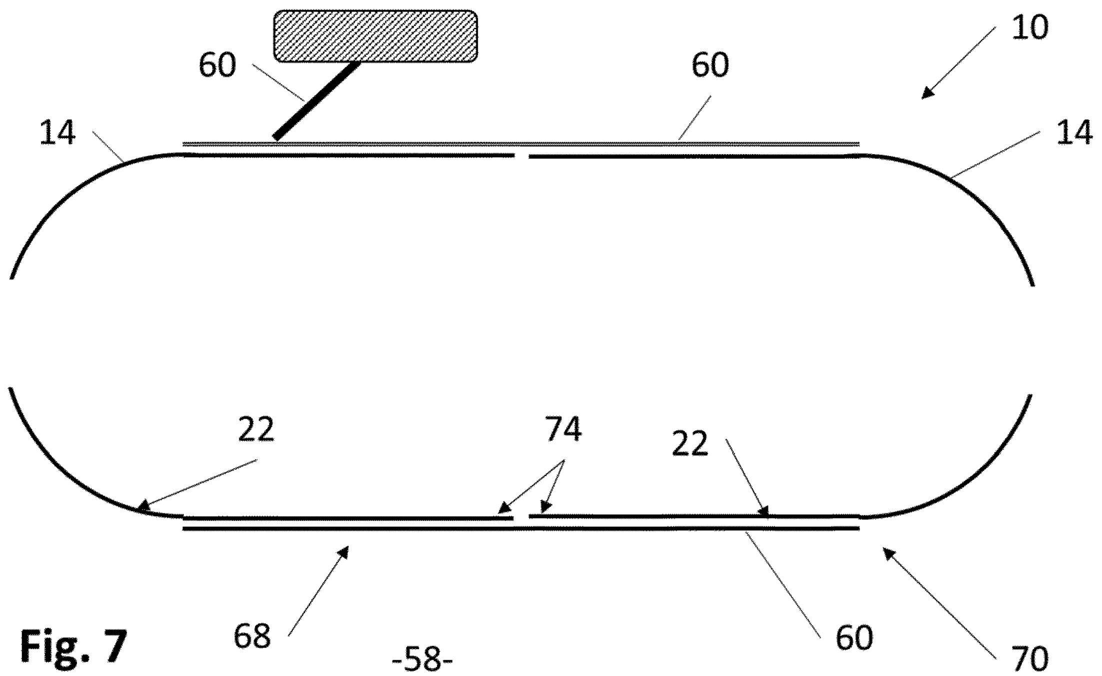


Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 22 17 7002

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 20 2020 106328 U1 (ADDITIVE SPACE GMBH [DE]) 10 February 2021 (2021-02-10) * paragraphs [0002], [0008], [0011], [0014], [0016], [0017], [0023], [0031]; figures 1,2 * -----	1-10	INV. F17C13/00
			TECHNICAL FIELDS SEARCHED (IPC)
			F17C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	11 November 2022	Fritzen, Claas

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