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(54) METHOD OF MANUFACTURING THE HOT PART OF A CYLINDER, OR THE HOUSING OF THE REGENERATOR, OF A HOT-GAS ENGINE

(71) We, N.V. PHILIPS' GLOEILAMPENFABRIEKEN, a limited liability Company, organised and established under the laws of the Kingdom of the Netherlands, of Emmasingel 29, Eindhoven, the Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of manufacturing the hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, comprises a metal shell, a ceramic heat-insulating lining on the inner side of the metal shell, and a double-walled metal cooling jacket on the outer side of the metal shell.

United Kingdom Patent Specification No. 1,454,298 describes a hot-gas engine in which at least that part of the metal cylinder of the engine which bounds the hot expansion space and at least that part of the metal regenerator housing in which the hot regenerator portion is accommodated are each provided on their inner side with a lining of heat-insulating material, notably a (glass) ceramic sleeve, and on the outer side with a cooling jacket in the form of, for example, a double-walled envelope in which cooling liquid circulates, or a heat pipe which effects the desired cooling by an evaporation/condensation process.

As a result of the combination of internal heat insulation and external forced cooling of the hot parts of the cylinder and the regenerator housing, these parts will have comparatively low temperatures during operation of the engine, and they can therefore be made of inexpensive construction materials.

In the known hot-gas engine referred to above, a glass ceramic layer is deposited directly on the inner surface of the cylinder and on the inner surface of the regenerator housing, or a glass ceramic insert is secured inside the cylinder and the regenerator housing, whilst the cooling jacket is mounted on the outer side of the cylinder or the regenerator housing.

The direct deposition of a glass ceramic layer has been found to be difficult and expensive. For a ceramic insert and for the cooling jacket, a tight fit relative to the cylinder and the regenerator housing is required. This necessitates a difficult and expensive machining operation, namely, a surface finishing for the outer side of the insert, the inner side and the outer side of the metal cylinder or housing, and the inner side of the cooling jacket.

According to the invention there is provided a method of manufacturing the hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, comprises a metal shell, a ceramic heat-insulating lining on the inner side of the metal shell, and a double-walled metal cooling jacket on the outer side of the metal shell, the method comprising the steps of forming the heat-insulating lining and the cooling jacket, arranging the lining inside the jacket so as to leave an annular space between the lining and the jacket, introducing molten metal into the annular space and subsequently allowing the metal to solidify in said space by cooling and so form the metal shell.

The metal shell is thus formed by a casting process, using the heat-insulating lining and the cooling jacket as a mould, with the annular space between the lining and the jacket forming the mould cavity. This casting of the metal shell produces a firm and complete contact between the shell and the heat-insulating lining on one side and the cooling jacket on the other side.

The molten metal shrinks upon solidification, whilst the ceramic lining, having a coefficient of expansion which is substantially equal to zero, substantially retains its original dimensions. As a result, the ceramic lining is subjected to a permanent compressive hoop stress which inhibits loosening of the lining from the metal shell.

In the case of the hot part of a cylinder of a hot-gas engine, by a suitable choice of metal for the shell it can be achieved that this compressive hoop stress in the ceramic lining is always greater than or equal to the tensile stress produced in the lining by high-pressure working medium during operation of the hot-gas engine.

During the introduction of the molten metal, the metal cooling jacket is heated and expands. During the cooling of the metal, the cooling jacket tends to shrink in radial directions through a distance which is proportional to its inner radial dimensions, but this is indirectly prevented by the ceramic lining. Because the solidifying metal can shrink only radially through a distance proportional to the width of the annular space between the lining and the jacket, which is due to the constant outer radial dimension of the ceramic lining, and because the cooling jacket tends to shrink over a distance proportional to its inner radial dimension, the cooling jacket will tightly surround the metal shell with considerable compressive stress. The resulting contact between the shell and the cooling jacket ensures a secure connection between these two parts and excellent transfer of heat between them.

The method in accordance with the invention requires no prior surface finishing of the component parts of the assembly. Moreover, no additional steps such as welding, brazing or glueing are required to ensure a gas-tight connection between the component parts.

The cooling jacket may be preheated prior to the introduction of the molten metal into the annular space. This reduces the risk of excessively fast and consequently irregular solidification of the liquid metal in the annular space.

The metal shell can be cast under vacuum, under atmospheric pressure, in which case air displaced in the annular space by the molten metal is vented from said space, or under a gas pressure higher than atmospheric pressure so that air inclusions in the molten metal are compressed.

Aluminium may be used to advantage for the metal shell. It is comparatively cheap, has a low melting point, a low yield point directly after casting and cooling, so that the temperature as well as the hoop stresses in the ceramic lining do not become excessively high, and it also has a low weight.

In order to ensure a reliable gas-tight connection between the aluminium shell and the metal cooling jacket in all circumstances, prior to the casting of the shell the cooling jacket may be provided with a surface layer of aluminium at least on its side which will be in contact with the shell.

Instead of aluminium it is possible to use a cast iron or a steel for the metal shell. These materials are also comparatively cheap.

The invention also provides the hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, is manufactured by the method according to the invention. It further provides a hot-gas engine comprising a cylinder of which the hot part is manufactured by the method according to the invention, or comprising a regenerator of which the housing is manufactured by the method according to the invention.

An example of the method according to the invention will be described in detail hereinafter with reference to the accompanying diagrammatic drawings, which are not to scale and in which

Fig. 1 is a sectional elevation of a heat-insulating lining arranged within a metal cooling jacket in readiness for the casting of the metal shell,

Fig. 2 is a view similar to Fig. 1 showing the casting of the shell,

Fig. 3 is a sectional elevation of a completed assembly of metal shell, heat-insulating lining and metal cooling jacket, and

Fig. 4 is a sectional elevation of a cooling jacket provided with an aluminium surface layer.

The reference numeral 1 in Fig. 1 denotes a ceramic lining of circular cross-section which is arranged within a double-walled steel cooling jacket 2 of circular cross-section comprising an inner wall 2*a* and an outer wall 2*b*, so that an annular space 3 is formed between the lining and the jacket. The lining and the jacket can be formed in any convenient manner.

The walls 2*a* and 2*b* of the cooling jacket 2 bound an annular space 4 through which a cooling medium such as water will flow, when the assembly is eventually in use, a cooling medium inlet 5 and outlet 6 being connected to the space 4.

Between the lower end of the ceramic lining 1 (as viewed in Fig. 1) and the lower end of the steel cooling jacket 2 there is provided a steel collar 7 having a central opening 8 which coincides with an opening 9 in the ceramic lining 1.

On the upper ends of the lining 1 and jacket 2 there is provided a steel cover plate 10 in which are formed a filling opening 11 and a plurality of vents 12 which are distributed around the plate 10 and coincide with the annular space 3 between the lining and the jacket.

If steel is chosen as the material for the metal shell which is to be formed between the ceramic lining 1 and the steel cooling jacket 2 in the present example, the cooling jacket 2 is preheated, by means of an electric heating element 13, to a temperature of, for example, 800°C. This causes the cooling jacket to expand in the radial direction.

Subsequently, as shown in Fig. 2, molten steel, designated 14, at a temperature of, for example, 1550°C, is poured from a tiltable crucible 15 through the filling opening 11 into the annular space 3, air displaced by the liquid steel escaping from the space 3 via the openings 12. The liquid steel is then allowed to solidify in the space 3 by cooling, so that a steel shell is formed to which the lining 1 and jacket 2 are rigidly connected. The lining and the jacket thus serve as a mould for the casting of the steel shell, the space 3 between the lining and the jacket forming the mould cavity.

Instead of casting under atmospheric pressure, vacuum casting or casting under high gas pressure can be used. In both cases casting can be carried out in a gas-tight chamber 16, denoted by a dotted line. In the case of vacuum casting, the chamber 16 is evacuated prior to casting by opening a valve 17 and operating a vacuum pumping installation 18, having an inlet 19 and an outlet 20. In the case of casting under pressure, for compressing gas inclusions (air bubbles) in the molten steel, high-pressure gas (for example, air at a pressure of 10 atm.) can be supplied from a gas cylinder 21 *via* a pressure-reducing valve 22 to the chamber 16 and, *via* the openings 11 and 12 to the space 3. Obviously, the high-pressure gas can be delivered directly by a compressor, if desired.

During casting, the ceramic lining 1 is heated by the molten steel, but it does not expand since its coefficient of expansion is substantially equal to zero. The assembly is subsequently allowed to cool to room temperature, the radial shrinkage of the solidifying steel 14 being limited because of the substantially constant outer diameter of the ceramic lining 1. This shrinkage is consequently related to the width S of the annular space 3 (Fig. 2).

During cooling, the cooling jacket 2 tends to shrink to an extent which is related to its inner diameter D (Fig. 2), but this also is inhibited by the ceramic lining 1. As a result, the cooling jacket 2 will tightly surround in a gastight manner the shell formed by the solidified steel, and the shell will in turn tightly surround the ceramic lining 1 in a gas-tight manner, with a resulting compressive hoop stress in the lining 1.

After the assembly has cooled, the portion of the steel cover plate 10 lying within the inner circumference of the lining 1 is cut away to obtain the finished assembly shown in Fig. 3. In Fig. 3 the assembly is shown in the position it will normally occupy when in use the hot part of a cylinder in a hot-gas engine, which position is inverted with respect to the position occupied during the casting of the metal shell. The space 30 inside the assembly serves as the hot working space of the cylinder, one end of the heater of the engine being connected to the opening 8. If the assembly is used as a housing for a regenerator of a hot-gas engine, the space 30 contains the filling mass of the regenerator and one end of the heater of the engine is again connected to the opening 8, whilst the engine cooler is connected to the opposite end of the assembly.

Instead of steel, iron or aluminium, for example, can be used for the metal shell. When using an aluminium alloy for example, Zn 10 Si 8 Mg and remainder Al, and the cooling jacket is made of, for example, steel or iron, the inner side of the cooling jacket, i.e. the side which will be in contact with the aluminium shell, may be provided with an aluminium surface layer prior to the casting of the shell in order to promote a good gas-tight connection between the cooling jacket and the aluminium shell. The aluminium surface layer can be formed by, for example, thermal zinc plating of the cooling jacket in a zinc bath, followed by annealing for one hour in a bath having the composition $Al\ Si_{12}$ at a temperature of 850°C to form an adhesive aluminium surface layer on the cooling jacket by thermal diffusion. If a metal collar is again provided between the ceramic lining and the cooling jacket, like the collar 7 in Figures 1 to 3, it is advantageous to provide this collar also with an aluminium surface layer first. The aluminium shell is then cast in the described manner.

Fig. 4 is a longitudinal sectional view of a cooling jacket 40 provided with aluminium surface layer 41.

Various modifications in the above process are possible without departing from the scope of the invention. For example, the cooling packet can be preheated by gas burners in a furnace instead of by an electrical heating element; the molten casting metal can be introduced into the space between the ceramic lining and the cooling jacket at a low level so that it rises in this space instead of being poured from above; the cover plate can be constructed so that it may be re-used or so that it may serve as a base plate for a group of hot-gas engine cylinders or regenerator housings each formed by the method according to the invention.

WHAT WE CLAIM IS:—

1. A method of manufacturing the hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, comprises a metal shell, a ceramic heat-insulating lining on the inner side of the metal shell, and a double-walled metal cooling jacket on the

outer side of the metal shell, the method comprising the steps of forming the heat-insulating lining and the cooling jacket, arranging the lining inside the jacket so as to leave an annular space between the lining and the jacket, introducing molten metal into the annular space and subsequently allowing this metal to solidify in said space by cooling and so form the metal shell.

2. A method as claimed in Claim 1, wherein the cooling jacket is preheated prior to the introduction of the molten metal into the annular space.

3. A method as claimed in Claim 1 or 2, wherein the casting of the metal shell is carried out under vacuum.

4. A method as claimed in Claim 1 or 2, wherein the casting of the metal shell is carried out under atmospheric pressure, air displaced in the annular space by the molten metal being vented from said space.

5. A method as claimed in Claim 1 or 2, wherein the casting of the metal shell is carried out under a gas pressure higher than atmospheric pressure in order to compress gas inclusions in the molten metal in the annular space.

6. A method as claimed in Claim 1, 2, 3, 4 or 5, wherein the metal used for the shell is an aluminium alloy.

7. A method as claimed in Claim 6, wherein prior to the casting of the metal shell the metal cooling jacket is provided with an aluminium surface layer at least on its side which will be in contact with the metal shell.

8. A method as claimed in Claim 1, 2, 3, 4 or 5, wherein the metal used for the shell is a cast iron or a steel.

9. A method of manufacturing the hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, comprises a metal shell, a lining ceramic heat-insulating lining on the inner side of the metal shell, and a double-walled metal cooling jacket on the outer side of the metal shell, the method being substantially as herein described with reference to the accompanying drawings.

10. The hot part of a cylinder, or the housing of a regenerator, of a hot-gas engine, which cylinder part, or regenerator housing, is manufactured in accordance with the method claimed in any of Claims 1 to 9.

11. A hot-gas engine comprising a cylinder of which the hot part is manufactured in accordance with the method claimed in any of Claims 1 to 9.

12. A hot-gas engine comprising a regenerator of which the housing is manufactured in accordance with the method claimed in any of Claims 1 to 9.

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1591261 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

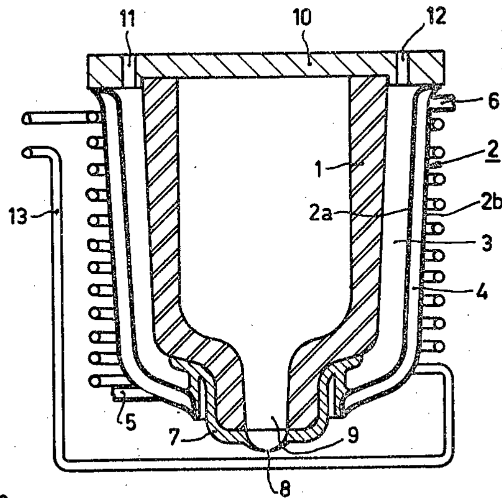

Fig. 1

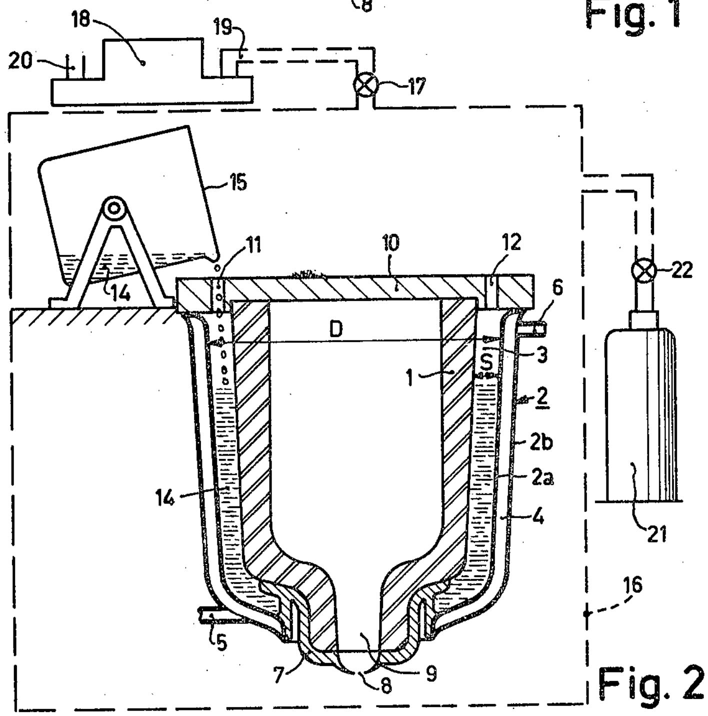

Fig. 2

1591261 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

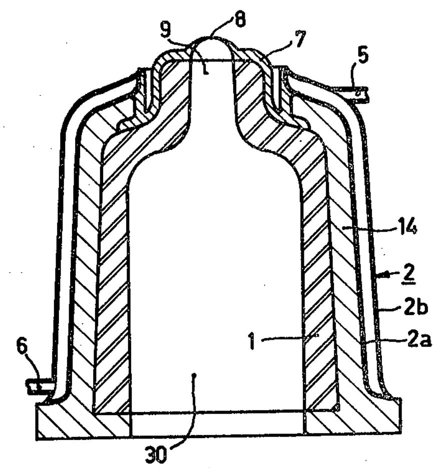

Fig. 3

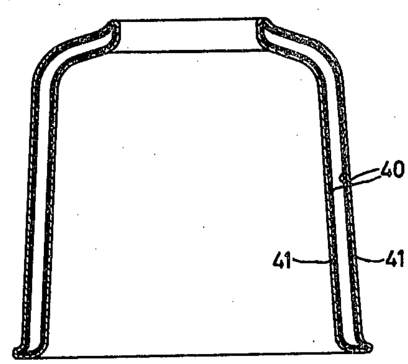

Fig. 4