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Kopchick et al.

(54) SAND CASTING A DIESEL PISTON WITH AN AS-CAST, REENTRANT COMBUSTION BOWL

(75) Inventors: **Joseph C. Kopchick**, Warren, MI (US); **Mark A. Osborne**, Grand Blanc, MI (US); **Richard D. Ricchi**, Lapeer, MI (US)

(73) Assignee: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

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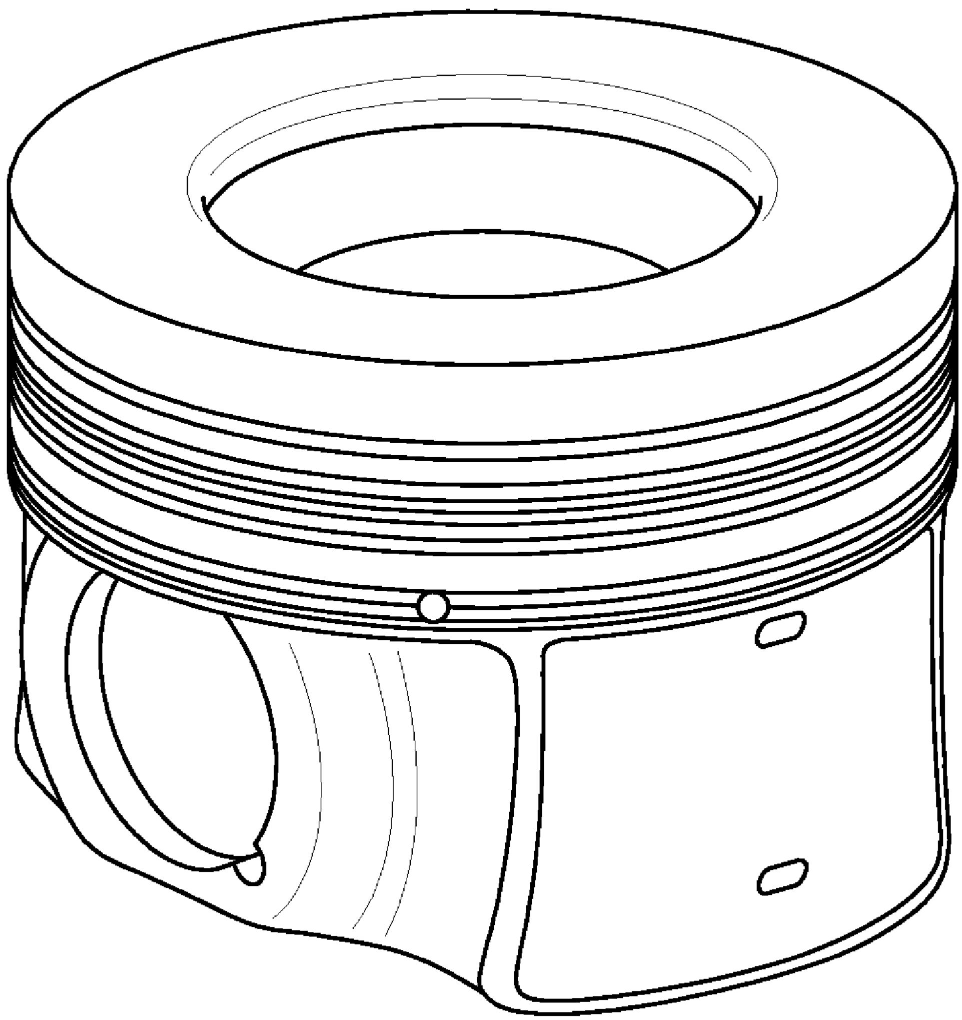
(57) **ABSTRACT**

A diesel engine piston and a method of making the piston. The method involves casting the piston with complex geometries, including undercut features. The casting uses an aggregate disposable mold that can be removed from the as-cast part. In one form, the complex geometry includes an undercut combustion bowl formed in the piston dome, while in another, it may include an internal cooling passage. The undercut bowl and internal passages may be produced using the aggregate disposable mold.



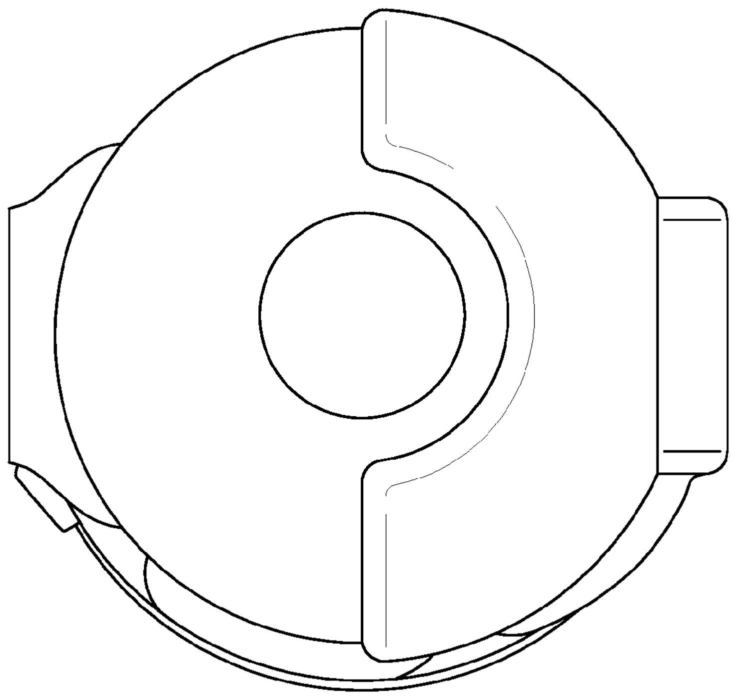


FIG. 1

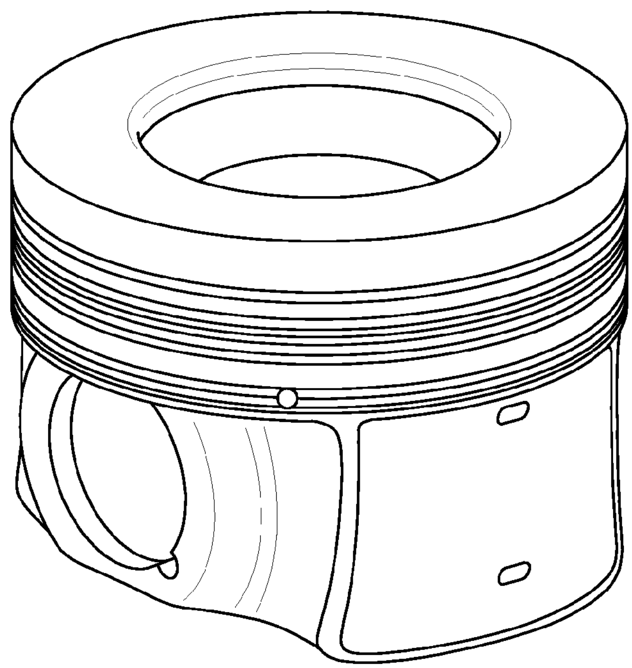


FIG. 2

SAND CASTING A DIESEL PISTON WITH AN AS-CAST, REENTRANT COMBUSTION BOWL

STATEMENT OF RELATED CASES

[0001] This application claims the benefit of Provisional Application Ser. No. 61/405,739, filed Oct. 22, 2010, entitled Sand Casting A Diesel Piston With An As-Cast, Undercut Combustion Bowl, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to devices and methods for casting engine components, and more particularly to an advanced diesel piston with complex features and a method of casting the same.

[0003] Pistons used in internal combustion engines are typically made up of a head (also called a dome), skirt, one or more ring grooves, and land between the grooves. More stringent emissions and efficiency requirements dictate that pistons will need to operate at closer to stoichiometric conditions, higher cylinder pressures, and in tighter packaging regimes in the future, which in turn will necessitate higher component loading and operating temperature conditions. This is particularly true for pistons used in diesel engines, which are increasingly being used to power passenger vehicles, in addition to being the predominant engine form for larger, commercial vehicles Likewise, more sophisticated dome designs are being developed to achieve a more thorough, efficient combustion process, which raises temperatures in the combustion chamber even more. These advanced dome designs, with their three-dimensional (3D) profiles, require more complex mold shapes, increasing the difficulty of casting the pistons, or necessitating the use of excessive machining to achieve the desired dome geometry.

[0004] Higher operating temperatures require the use of materials capable of operating under those conditions. Cooling schemes have been employed as a way to enhance the life of pistons and related high-temperature components. One way of achieving cooling is routing engine lubricant, which is already present, through passages formed in the piston. There is a significant benefit to cooling the dome because it is exposed directly to the combustion process. However, adding cooling channels further increases the difficulty of casting the piston.

[0005] Traditional nonexpendable forms of casting, such as permanent mold casting, are not well-suited to forming complex shapes. In particular, the permanent nature of the mold, coupled with the reentrant regions present in some shapes, such as the 3D dome shapes discussed above, limit the ability to retract the part once the casting has solidified. As a result, extensive machining of the casting is needed to produce the complex shapes. This additional machining contributes to the complexity and cost of permanent mold casting approaches. Part quality may also suffer with permanent mold casting. The presence of risers may impact the piston's microstructure and the amount of grain refinement that is achievable. For example, the relatively large thermal mass of the large risers tends to slow down solidification of the cast component, whereas faster cooling and the accompanying improved mechanical properties as evidenced by the presence of smaller secondary dendrite arm spacing (SDAS) are often desirable. There can be as much as a 20% difference in mechanical properties comparing the in-gate location to the riser sides.

[0006] One embodiment of the top view of a piston as cast is shown in FIG. **1**. FIG. **2** shows a perspective view of the piston after machining, clearly evidencing the extensive machining required to produce the dome.

[0007] To overcome the shape limitations of permanent mold casting, other approaches may be employed, including various forms of expendable-mold castings, such as investment (or lost-wax) casting, sand casting, or the like. A variant of the sand casting approach, known as salt core casting, employs techniques generally similar to sand casting, except that a water-soluble salt is employed for internal mold geometries, rather than a green or dry sand. Once the part is made, the salt mold can be washed away with water without subjecting the part to any additional thermal loads. Salt core casting has storage and handling concerns that lessen its appeal.

[0008] Another approach that has been used to create an as-cast dome is semi-permanent mold casting. This approach still requires that the combustion bowl be machined. As with the permanent mold castings discussed above, a significant amount of risering off the dome is also required. Furthermore, higher output (i.e., high-performance) pistons may also require bowl rim remelting. These additional processes add significantly to the cost of the piston. This is especially true for remelting work and bowl machining costs, and even more so for pistons configured to operate under high temperature and pressure conditions, such as high output diesel pistons. Such pistons may operate at about 200 bar cylinder pressure and about 400 C, and involve the use of steel forgings at an even more significant cost impact.

SUMMARY OF THE INVENTION

[0009] One aspect of the invention is a method of making a diesel piston. In one embodiment, the method includes providing a pattern for the piston, the pattern including a dome and a reentrant bowl; forming a piston mold around the pattern, the mold comprising an aggregate material and a binder; removing the pattern from the piston mold; introducing molten metal into the piston mold; contacting the piston mold with a solvent for the binder and removing the binder and the aggregate; cooling the molten metal; and solidifying the molten metal to form the piston with the dome and the reentrant bowl without need for post-casting processing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The following detailed description of specific embodiments can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

[0011] FIG. **1** is top view of a diesel piston of the present invention in the current as-cast condition where the dome is completely cast over, showing excessive risers; and

[0012] FIG. **2** is a perspective view of the diesel piston of FIG. **1** after final machining.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] An ablation casting approach can be used to produce a piston with a dome incorporating an as-cast, reentrant bowl, and an optional internal cooling passage. Ablation casting uses inorganic (i.e., water soluble) cores, and water is sprayed on the mold which slowly washes away (hence the term "ablation"), rapidly cooling the casting. The rapid cooling results in improved material properties. Ablation casting allows complex parts to be produced with a fine solidification microstructure. The application of water allows component solidification and cooling to be controlled separately from one another (e.g., by applying water to specific areas of the casting before others or by applying different amounts of water to different areas). By providing the high solidification rates and refined microstructure that are often needed to achieve the through-section higher mechanical properties (such as tensile and fatigue properties at room temperature and elevated temperatures), ablation casting allows complex parts to be formed, such as those combining both thin and thick sections, as well as those with complex internal cores. The through-section properties are superior compared to those made using bowl rim re-melting, which only provides the desirable fine microstructure to a depth only slightly below the surface (e.g., a few mm).

[0014] The ablation casting process is described generally in U.S. Pat. No. 7,121,318, which is incorporated by reference herein. A pattern is formed from a material, and a mold is formed around at least a portion of the pattern. The mold is made of aggregate material and a binder. The pattern is removed from the mold, and molten metal is then introduced into the mold. The mold is contacted with a solvent, and the molten metal is cooled so that it at least partially solidifies to form a casting. The cooling step includes contacting a shell of solidified metal around the molten metal with the solvent.

[0015] Ablation casting has not been used to cast diesel pistons in general, and more particularly diesel pistons with a reentrant bowl.

[0016] U.S. Pat. Nos. 7,164,963, 7,618,823, and 7,225,049 describe analysis methods for lost foam casting (a type of ablation casting), each of which is incorporated by reference herein.

[0017] The use of ablation casting offers the possibility of casting the piston with a near-net-shape dome without the significant post-casting processing and/or machining required by other processes. Thus, the dome and combustion bowl can be cast simultaneously. In a particular form, the reentrant bowl and internal passages would be produced by means of an aggregate disposable mold that could be produced by conventional core technology with retractable tooling in the molding die. In the present context, the aggregate form of the molding media includes, but is not limited to, silica sand, zircon sand, chromite sand, ceramic micro spheres, or the like.

[0018] The benefits associated with the present invention include, but are not limited to, one or more of the following: reduced machining costs, refined as-cast microstructure for improved mechanical properties, taking advantage of a sand (or related) molding process to tailor a reentrant region in the dome, reducing casting weight, and eliminating the need for an internal salt core. The traditional salt core could be replaced with an aggregate core of the same material as the piston mold.

[0019] In one form, sand casting can be used to produce the piston of the present invention. This process would substantially reduce the massive risers that are typically used with permanent mold casting, resulting in improved material yield. Furthermore, the high cooling rate inherent in ablation casting makes it easier to tailor the process to achieve a refined microstructure with improved material properties. These improved material properties should provide a stronger piston as a whole, as well as the needed piston bowl rim strength (without having to re-melt this area) to pass rigorous head gasket validation tests consistently.

[0020] In one particular form, the mold can be made from sand that is capable of ablation casting such that complex dome shapes, including those with undercut and internal cooling passage features, may be easily and inexpensively manufactured. As such, a sand mold may be used as part of the ablation process.

[0021] Improved material yield can be realized by eliminating the large risers that are often used as part of a permanent mold casting operation. In particular, by using an ablation casting approach, the inherently high cooling rate can allow the piston being formed to have a homogeneous microstructure and related structural properties.

[0022] In addition to the finer microstructure and enhanced piston properties, use of the ablation process permits much finer details to be cast into the part, including intricate cooling channels. The process reduces or eliminates the need for post-cast machining in the area around the dome, particularly as it relates to the reentrant region. Because the ablation casting is production-ready, scaling up to manufacture large quantities of pistons or related components is comparatively simple. An aggregate disposable mold could be employed to allow the combustion bowl of the piston dome and a lubricating and cooling oil gallery to be formed as part of the casting.

[0023] Employing ablation casting for diesel pistons helps to achieve a significant microstructural refinement by reducing or eliminating the need for expensive secondary post-casting processing such as machining or remelting. In situations where a refined microstructure is desired, such as the bowl edge or other complex 3D regions of the piston, tungsten inert gas (TIG) or laser remelting can be done locally (in the dome reentrant region). Subsequent machining, such as to yield proper shape of the bowl edge, may be similarly reduced or eliminated.

[0024] This invention takes advantage of the ablation casting process to eliminate the need for large risers at the piston dome. The ability to cool the dome more quickly and uniformly should enhance mechanical properties. In particular, the disposable aggregate mold should allow the combustion bowl to be formed as-cast. Furthermore, the aggregate mold material may also be used to form the oil gallery behind the top ring groove, eliminating the need for a salt core. This additionally allows for rapid prototyping of pistons, which can improve general development testing.

[0025] It is noted that terms like "preferably," "commonly," and "typically" are not utilized herein to limit the scope of the claimed invention or to imply that certain features are critical, essential, or even important to the structure or function of the claimed invention. Rather, these terms are merely intended to highlight alternative or additional features that may or may not be utilized in a particular embodiment of the present invention.

[0026] For the purposes of describing and defining the present invention it is noted that the term "device" is utilized herein to represent a combination of components and individual components, regardless of whether the components are combined with other components. For example, a "device" according to the present invention may comprise an electrochemical conversion assembly or fuel cell, a vehicle incorporating an electrochemical conversion assembly according to the present invention, etc.

[0027] For the purposes of describing and defining the present invention it is noted that the term "substantially" is utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

[0028] While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes may be made without departing from the scope of the invention, which is defined in the appended claims.

What is claimed is:

1. A method of making a diesel piston comprising:
providing a pattern for the piston, the pattern including a dome and a reentrant bowl;
forming a piston mold around the pattern, the mold comprising an aggregate material and a binder;
removing the pattern from the piston mold;
introducing molten metal into the piston mold;
contacting the piston mold with a solvent for the binder and removing the binder and the aggregate;
cooling the molten metal; and
solidifying the molten metal to form the piston with the dome and the reentrant bowl without need for post-casting processing.

2. The method of claim **1** wherein the binder is water soluble, and wherein the solvent is water.

3. The method of claim **1** wherein cooling the molten metal and solidifying the molten metal are controlled separately.

4. The method of claim **3** wherein cooling the molten metal and solidifying the molten metal are controlled separately by applying the solvent to one area of the piston before other areas or by applying different amounts of solvent to different areas of the piston.

5. The method of claim **1** wherein the aggregate material is silica sand, zircon sand, chromite sand, ceramic micro spheres, or combinations thereof.

6. The method of claim **1** wherein cooling the molten metal comprises contacting a shell of solidified metal around the molten metal with the solvent.

7. The method of claim **1** further comprising:
providing a mold for an internal cooling passage, the mold for the internal cooling passage comprising a second aggregate material and a second binder;
placing the mold for the internal cooling passage in the piston mold before introducing the molten metal into the piston mold; and
contacting the mold for the internal cooling passage with a solvent for the second binder and removing the second binder and the second aggregate.

8. The method of claim **6** wherein the second aggregate material and the second binder are the same as the aggregate material and the binder for the piston mold.

9. The method of claim **1** wherein contacting the piston mold with a solvent for the binder comprises spraying the piston mold with the solvent.

10. A method of making a diesel piston comprising:
providing a pattern for the piston, the pattern including a dome and a reentrant bowl;
forming a piston mold around the pattern, the mold comprising an aggregate material and a water-soluble binder;
removing the pattern from the piston mold;
introducing molten metal into the piston mold;
contacting the piston mold with water and removing the binder and the aggregate;
cooling the molten metal; and
solidifying the molten metal to form the piston with the dome and the reentrant bowl without need for post-casting processing.

11. The method of claim **10** wherein cooling the molten metal and solidifying the molten metal are controlled separately.

12. The method of claim **11** wherein cooling the molten metal and solidifying the molten metal are controlled separately by applying water to one area of the piston before other areas or by applying different amounts of water to different areas of the piston.

13. The method of claim **10** wherein the aggregate material is silica sand, zircon sand, chromite sand, ceramic micro spheres, or combinations thereof.

14. The method of claim **10** wherein cooling the molten metal comprises contacting a shell of solidified metal around the molten metal with water.

15. The method of claim **10** further comprising:
providing a mold for an internal cooling passage, the mold for the internal cooling passage comprising a second aggregate material and a second binder;
placing the mold for the internal cooling passage in the piston mold before introducing the molten metal into the piston mold; and
contacting the mold for the internal cooling passage with a solvent for the second binder and removing the second binder and the second aggregate.

16. The method of claim **15** wherein the second aggregate material and the second binder are the same as the aggregate material and the binder for the piston mold.

17. The method of claim **10** wherein contacting the piston mold with water comprises spraying the piston mold with water.

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