

**FIBER REINFORCED CERAMIC MATRIX COMPOSITE CYLINDER
HEAD AND CYLINDER HEAD LINER FOR AN INTERNAL
COMBUSTION ENGINE**

5

TECHNICAL FIELD

This invention relates to components of internal combustion engines and, more particularly, to an all ceramic cylinder head or a fiber reinforced ceramic matrix composite
10 liner for internal combustion engine comprising a cylinder head made of structural fiber reinforced ceramic matrix composite.

BACKGROUND OF THE INVENTION

A typical internal combustion engine comprises an engine block containing one or
15 more cylinders in which pistons move up and down as the result of the burning of fuel therein. The cylinders are covered and closed by a cylinder head 10 as shown in Figures 1 and 2. The burning of the fuel under compression releases energy as motion and heat. Accordingly, the parts of the engine tend to get very hot. To prevent metal damage from over-heating and problems of lubrication break-down and possible engine seizure from
20 excessive thermal expansion of parts, the heat must be conducted away so as to limit the operating temperature of the engine to design standards. This is normally done in one of two ways. As shown in Figure 1, the cylinder head 10 can have a water jacket 12 built into it wherein the water jacket 12 is connected via the connecting tubes 30,32 to the water circulated through the block and an air-cooled radiator. As shown in Figure
25 2, the cylinder head 10 can incorporate fins 14 which provide a large surface area to radiate heat directly to air passing therethrough. Motorcycles, lawnmowers and the like, tend to use the fins 14 while automobile and truck engines favor a water jacket 12 due to the high heat loads generated in their operating environment in conjunction with allowable under-hood temperature requirements. In addition, the water jacket 12

provides a heat source for the vehicle's heating, ventilation and air conditioner (HVAC) system.

Wherefore, it is an object of the present invention to provide a ceramic cylinder head or headliner fabricated of a structural fiber reinforced ceramic matrix composite material for an internal combustion engine which includes provision for reducing its temperature level at the outer surface thereof.

It is another object of the present invention to provide a ceramic cylinder head or headliner fabricated of a structural fiber reinforced ceramic matrix composite material for an automobile which can be positioned under an automobile hood without damaging other vehicle systems from radiated heat.

It is still another object of the present invention to provide a ceramic cylinder head or headliner fabricated of a structural fiber reinforced ceramic matrix composite material for an automobile which provides or allows for hot water for a passenger compartment heating system.

Other objects and benefits of this invention will become apparent from the description which follows hereinafter when read in conjunction with the drawing figures which accompany it.

DISCLOSURE OF THE INVENTION

The foregoing objects have been achieved by the ceramic cylinder head and ceramic head liner for an internal combustion engine of the present invention comprising a cylinder head made of a generic fiber system disposed throughout a pre-ceramic resin in its ceramic state and means for transferring heat from the cylinder head.

In the preferred embodiment, the means for transferring heat from the cylinder head will depend on the specific application for which the engine is designed. Motorized vehicle applications typically include the use of a liquid cooling system to remove excess heat from the head which also provides a heat source for the passenger compartment heating system, while small utility engines are typically air cooled.

In one embodiment, the means for transferring heat from the cylinder head comprises radiating fins formed in the top surface of the cylinder head for transferring heat to air surrounding the fins.

In another embodiment, the means for transferring heat from a top surface of the
5 cylinder head comprises a metal heat sink attached to the top surface, the heat sink including radiating fins for transferring heat to air surrounding the fins. In one embodiment for producing hot water as a byproduct, the means for transferring heat from the cylinder head comprises a metal water jacket formed onto the top surface wherein the water jacket has an inlet pipe and an outlet pipe for passing engine coolant
10 or some other fluid used in the passenger compartment heating system therethrough. This embodiment can be cast directly onto the ceramic cylinder head.

The fourth embodiment is a bonded in FRCMC cylinder head liner for use in a water cooled cylinder head.

The fifth embodiment is a mechanically trapped FRCMC cylinder head liner for air
15 cooled cylinder head applications.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified cross section of a prior art cylinder head with a water jacket incorporated therein, representative of typical automotive applications.

20 Figure 2 is a simplified cross section of a prior art cylinder head with air-cooling this incorporated therein, typical in small utility engine applications.

Figure 3 is a simplified cross section of a ceramic cylinder head with integral air-cooling fins incorporated therein according to a first embodiment of the present invention.

25 Figure 4 is a simplified cross section of a ceramic cylinder head with air-cooling fins of metal bolted thereon as an add-on item according to a second embodiment of the present invention.

Figure 5 is a simplified cross section of a ceramic cylinder head incorporated into

a cast metal water jacket according to a third embodiment of the present invention.

Figure 6 is a simplified cross section of a ceramic cylinder head incorporated into a cast metal water jacket according to a fourth embodiment of the present invention.

Figure 7 is a simplified cross section of a ceramic cylinder head incorporated into
5 a cast metal water jacket according to a fifth embodiment of the present invention.

BEST MODES FOR CARRYING OUT THE INVENTION

In one embodiment of the present invention as depicted in Figure 3, a cylinder head 10' is formed out of a structural fiber reinforced ceramic matrix composite (FRCMC) material. In particular, the cylinder head 10' can be made of a structural fiber reinforced ceramic matrix composite material comprising a polymer-derived ceramic resin or a cementitious resin that has been modified to emulate polymer composite processing techniques having fibers of a generic fiber system disposed throughout. The preferred FRCMC material employs any of several pre-ceramic resins commercially available such
15 as silicon-carboxyl resin (sold by Allied Signal under the trade name Blackglas), alumina silicate resin (sold by Applied Poleramics under the product designation C02), or monoaluminum phosphate (also known as monoalumino phosphate) resin combined with a generic fiber system such as, but not limited to, alumina, Altex, Nextel 312, Nextel 440, Nextel 510, Nextel 550, silicon nitride, silicon carbide, HPZ, graphite, carbon, and
20 peat. To add additional toughness qualities to the material, the fiber system can be first coated to 0.1-5.0 microns thickness with an interface material such as, but not limited to, carbon, silicon nitride, silicon carboxyl, silicon carbide or boron nitride or a layered combination of one or more of the above interfacial materials. The interface material prevents the resin from adhering directly to the fibers of the fiber system. Thus, when
25 the resin is converted to a ceramic matrix, there is a slight play between the ceramic and fibers imparting the desired qualities to the final FRCMC material.

Additionally, it is recommended that the surface of the FRCMC head or headliner which faces the combustion environment cylinder bore can be coated with a

wear-resistant coating for resisting corrosive materials of the combustion via commercially available erosion-resistant coatings, such as plasma sprayed alumina powder or physical vapor deposition of a titanium nitride, or with conventional plasma spray techniques and of materials identified in the co-pending application entitled

5 REDUCING WEAR BETWEEN STRUCTURAL FIBER REINFORCED CERAMIC MATRIX COMPOSITE AUTOMOTIVE ENGINE PARTS IN SLIDING CONTACTING RELATIONSHIP by the inventors herein, serial number _____ filed on even date herewith. In a first embodiment for coating the surface of the FRCMC head or headliner which faces the combustion environment with a wear-resistant coating, a woven or non-woven cloth

10 mat of fibers is employed. In this embodiment, the contacting surfaces of the structural fiber reinforced ceramic matrix composite component are covered with an erosion-resistant coating which bonds tightly to the wearing surface of the FRCMC structures. For this purpose, the erosion-resistant coating preferably comprises Mullite (i.e. alumina silicate Al_2Si_4), alumina (i.e. Al_2O_3), or equivalent, applied via a plasma spray

15 generally according to techniques well known to those of ordinary skill in the art.

The erosion-resistant coating is applied as follows. Prior to the application of the erosion-resistant coating, all holes for spark plugs, valves, wrist pins, etc. are machined. Commercial grade diamond cutting tools are recommended for this purpose. Any other machining as described later is also done at this point. Upon the completion of the

20 machining processes, if any, all sharp edges on the surface of the part are knocked down using diamond paper.

If the part has been machined, it is placed in an oven for a time and temperature adequate to assure "burn off" of any of the cutting lubricants used in the machining process. (Typically 2 hours at 700°F , but is lubricant dependent.)

25 The key is getting the erosion-resistant coating to bond to the FRCMC structure. If the surface of the FRCMC structure is not properly prepared, the erosion-resistant coating can simply flake off and provide no long-term protection. In the preferred approach, the surface of the FRCMC structure is lightly grit-blasted to form small

divots within the ceramic matrix of the FRCMC structure. It is also believed that the light grit blasting exposes hairs or whiskers on the exposed fiber of the generic fiber system which the erosion-resistant coating can grip and adhere thereto. Typical grit blasting that has proved successful is 100 grit @ 20 PSI.

5 According to a second possible approach, the surface of the FRCMC structure can be provided with a series of thin, shallow, regularly-spaced grooves similar to fine "threads" of a nut or bolt, which the erosion-resistant coating can mechanical lock into. Essentially, the surface is scored to provide a roughened surface instead of a smooth surface. The depth, width, and spacing of the grooves is not critical and can be
10 determined for each part or component without undue experimentation. In general, the grooves should be closely spaced so as to minimize any large smooth areas of the surface where there is a potential for the erosion-resistant coating to lose its adhesion and flake off. Thus, over-grooving would be preferable to under-grooving the surface with the exception that over-grooving requires the application of additional wear material
15 to provide a smooth wear surface after final grinding. The grooves should be shallow so as to provide a mechanical locking area for the erosion-resistant coating without reducing the structural strength of the underlying FRCMC structure to any appreciable degree.

After surface preparation, the part is cleaned by using clean dry compressed air
20 and then loaded in an appropriate holding fixture for the plasma spray process. Direct air blowers are used to cool the opposite side of the part during the application of the erosion-resistant coating.

The plasma sprayed erosion-resistant coating is then applied using a deposition rate set to 5 grams per minute or more. The holding fixture speed, plasma gun movement
25 rate across the surface, and spray width are set to achieve a barber pole spray pattern with 50% overlap. The spray gun is set relative to the sprayed surface from 0.1 inches to 3 inches away. Particle sizes used for this process range from 170 to 400 mesh. Enough material is applied to allow for finish machining.

After the application of the erosion-resistant coating, the coated surface is smoothed out with diamond paper or an appropriate form tool (commercial grade diamond tools recommended) to achieve the final surface contour.

In an alternative embodiment, the erosion-resistant material in powder form may be dispersed within the matrix material (i.e. the resin) prior to forming the component for improved wear resistance. Alternatively, the plasma sprayed coating can be applied and then the part with the erosion-resistant coating attached can be further reinfiltrated with the pre-ceramic polymer resin and then converted to a ceramic state. The result is an additional toughening of the coating by essentially incorporating the coating into the mixed or combined ceramic matrix composite formed from the combination of the FRCMC and a ceramic matrix reinforced monolithic wear coating integrally bound together by the common ceramic matrix.

Further, the surface of the FRCMC head or headliner which faces the combustion environment can be coated with a wear-resistant coating for resisting corrosive materials of the combustion via commercially available erosion-resistant coatings, such as plasma sprayed alumina powder or physical vapor deposition of a titanium nitride, or with conventional plasma spray techniques and of materials identified in the co-pending application entitled METHODS AND APPARATUS FOR MAKING CERAMIC MATRIX COMPOSITE LINED AUTOMOTIVE PARTS AND FIBER REINFORCED CERAMIC MATRIX COMPOSITE AUTOMOTIVE PARTS by the inventors herein, serial number _____ filed on even date herewith. A first aspect is a method for forming a metal part having a breakage resistant ceramic liner comprising the steps of, forming a metal part having a mating surface for receiving the liner; forming a liner of a ceramic material containing pores; filling the pores with a pre-ceramic polymer resin; firing the pre-ceramic polymer resin saturated liner at a temperature and for a time (designated by the resin manufacturer) which converts the resin into a ceramic within the pores; and, bonding the ceramic liner to the mating surface of the metal part.

In one embodiment, the step of forming the liner of a ceramic material containing

pores comprises pouring an inexpensive castable cementitious slurry into a liner-shaped mold, firing the molded slurry material for a time and at a temperate which converts it into a handleable pre-ceramic form, removing the pre-ceramic form from the mold, and firing the pre-ceramic form for a time and at a temperate which converts it into a ceramic form containing pores formed by out-gassing. And, the step of filling the pores with a polymer-derived ceramic resin comprises placing the liner into a bath containing a liquid pre-ceramic polymer resin until the pores are saturated with the resin. Preferably, the resin is silicon-carboxyl resin (sold by Allied-Signal under the trade name Blackglas).

In a second embodiment, the step of forming the liner of a ceramic material containing pores comprises positioning a fiber preform into a liner-shaped mold to occupy 30% to 60% of the volume of the mold, forcing a liquid pre-ceramic polymer resin through the preform to fill the remaining volume of the mold with the liquid pre-ceramic polymer resin, firing the mold for a time and at a temperate which converts it into a handleable pre-ceramic form, removing the pre-ceramic form from the mold, and firing the pre-ceramic form for a time and at a temperate which converts the liquid pre-ceramic polymer resin into a ceramic matrix composite form containing pores formed by out-gassing. Preferably, the liquid pre-ceramic polymer resin is silicon-carboxyl resin, e.g. Blackglas.

A second aspect of the present invention is a method for forming a metal part having a breakage resistant ceramic liner comprising the steps of, forming a liner of a ceramic material containing pores; filling the pores with a pre-ceramic polymer resin; firing the pre-ceramic polymer resin saturated liner at a temperature and for a time (as designated by the resin manufacturer), which converts the resin into a ceramic within the pores; positioning the liner within a mold for the metal part with the mating surface of the liner facing into a portion of the mold to be occupied by the metal forming the part; and, filling the mold with molten metal to form the part.

As with the first aspect, the step of forming the liner of a ceramic material containing pores can comprise either approach described above. And, the step of filling

the pores with a polymer-derived ceramic resin again comprises placing the liner into a bath containing a liquid pre-ceramic polymer resin until the pores are saturated with the resin; firing the pre-ceramic polymer resin saturated liner at a temperature and for a time which converts the resin into a ceramic within the pores.

5 In all cases where the pores formed by outgassing are filled, it is preferred to repeat the pore-filling and re-heating process several times to virtually totally remove the pores from the final product.

In another aspect of the present invention, a method of making a fiber reinforced ceramic matrix composite automotive part is disclosed comprising the steps of, forming
10 a preform in the shape of the part from fibers of a generic fiber system employable in fiber reinforced ceramic matrix composites; placing the preform in a cavity of a mold having the shape of the part; forcing a liquid polymer-derived ceramic resin through the cavity to fill the cavity and saturate the preform; heating the mold at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the liquid
15 polymer-derived ceramic resin-saturated preform into a polymer composite part; removing the polymer composite part from the mold; and, firing the polymer composite part in an inert atmosphere at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the polymer-derived ceramic resin into a ceramic whereby the polymer composite part is transformed into a fiber reinforced ceramic matrix
20 composite part.

Preferably, the method also includes the steps of, immersing the fiber reinforced ceramic matrix composite part containing pores formed by outgassing during firing into a bath of the liquid polymer-derived ceramic resin to fill the pores with the liquid polymer-derived ceramic resin; firing the fiber reinforced ceramic matrix composite part
25 in an inert atmosphere at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the polymer-derived ceramic resin in the pores into a ceramic; and, repeating this process until the pore density within the final fiber reinforced ceramic matrix composite part is less than a pre-established percentage

affording maximum
strength to the part.

The preferred method is also adaptable to forming hollow parts such as engine manifolds by employing the steps of, forming a first preform in the shape of a lower
5 portion of the manifold from fibers of a generic fiber system employable in fiber reinforced ceramic matrix composites; placing the first preform in a cavity of a first mold having the shape of the lower portion of the manifold; forcing a liquid polymer-derived ceramic resin through the cavity to fill the cavity and saturate the first preform; heating
10 the first mold at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the liquid polymer-derived ceramic resin-saturated first preform into a first polymer composite part; removing the first polymer composite part from the mold; forming a second preform in the shape of an upper portion of the manifold from fibers of the generic fiber system; placing the second preform in a cavity of a second mold having the shape of the upper portion of the manifold; forcing the liquid
15 polymer-derived ceramic resin through the cavity to fill the cavity and saturate the second preform; heating the second mold at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the liquid polymer-derived ceramic resin-saturated second preform into a second polymer composite part; removing the second polymer composite part from the mold; fitting the first polymer composite part
20 and the second polymer composite part together along mating edges to form the manifold as a hollow conduit-shaped part; and, firing the polymer composite manifold in an inert atmosphere at a temperature and for a time associated with the polymer-derived ceramic resin which transforms the polymer-derived ceramic resin into a ceramic whereby the polymer composite manifold is transformed into a fiber reinforced ceramic matrix
25 composite manifold and the upper portion and the lower portion are fused together along the mating edges.

Pores formed by outgassing are preferably sealed in the manner described above to give maximum strength to the resultant manifold and seal any leakage that may exist along

the mating edges.

Where the manifold is an exhaust manifold to be internally filled with a ceramic foam catalyst substrate structure the process and required tooling can be greatly simplified by prior to the step of placing the second preform in a cavity of a second mold
5 having the shape of the upper portion of the manifold additionally including the steps of, placing the first preform as part of a cavity-defining wall of the second mold; and, placing the ceramic foam catalyst substrate structure in the first preform whereby the first preform and the ceramic foam catalyst substrate structure in combination form part of the cavity of the second wall.

10 Referring back to Figure 3, fins 14 of the cylinder head 10' are formed integral to the cylinder head 10' itself, thus providing a single FRCMC unit. Additionally, an erosion-resistant coating 28 is applied via plasma spray techniques, to the combustion facing side of the head to enhance endurance capabilities. The fins 14 are not as breakage resistant as metal fins. Thus, this embodiment is not preferred for most
15 applications.

In the cylinder head 10' of Figure 4, fins 14 are also employed; but, in this case, they are part of a metal heat sink 16 that is bolted to the top of the cylinder head using the bolts 18 employed to bolt the cylinder head 10' to the engine block. The heat sink 16 and its fins 14 can be welded steel, cast aluminum or iron, or the like, as best suited
20 to the particular application. Additionally, an erosion resistant coating 28 is applied, via plasma spray techniques, to the combustion facing side of the ceramic head to enhance endurance capabilities. This embodiment is preferred for small engine applications such as lawn and garden equipment.

There are three preferred embodiments for the application of the present invention
25 to large powerplants such as those found in motorized vehicles and those used as a stationary power source.

The first of these is depicted in Figure 5. The cylinder head 10' is of metal having a metal water jacket 12 cast onto it as well as an integrally cast-in headliner 11. The

water jacket 12 has an inlet pipe 30 and an outlet pipe 32 in the usual manner. Since the cylinder head headliner 11 is a ceramic, it can be subjected to molten metal during the casting forming process of the water jacket without harm. Thus in a preferred construction approach, one would first make the ceramic headliner 11. The headliner 11
5 would then be put into a mold for the water jacket 12 as part of the walls of the mold cavity. By pouring molten metal into the mold, the water jacket 12 would be cast directly onto the cylinder head headliner 11 conforming to the contacting surface for maximum structural integrity. Additionally, an erosion resistant coating 28 is applied, via plasma spray techniques, to the combustion facing side of the head/headliner to enhance
10 endurance capabilities.

The second of the preferred embodiments is depicted in Figure 6. The cylinder head headliner 11' is made in the manner described above. A separate, conventional metal head 10'' including a water jacket 12 is fabricated using current state of the art techniques with the exception that the combustion chamber region of the head is left
15 oversized with an inner contour which matches the non-combustion chamber facing side contour of the FRCMC headliner 11'. The FRCMC headliner is then adhesively bonded in place using commercially available high temperature adhesives or silicone rubbers 34 including, but not limited to, PERMATEx ULTRA COPPER gasket material. Additionally, an erosion resistant coating 28 is applied, via plasma spray techniques, to the
20 combustion facing side of the FRCMC headliner to enhance endurance capabilities.

The third of the preferred embodiments is depicted in Figure 7. The cylinder head headliner 11' is made in the manner previously described. A separate, conventional metal head 10''' including a water jacket 12 is fabricated using current state of the art techniques with the exception that the combustion chamber region of the head is left
25 oversized with an inner contour which matches the non-combustion chamber facing side contour of the FRCMC headliner 11'. The FRCMC headliner is then mechanically trapped between the cylinder block (not shown) and the conventional metal head 10''' by the use of the headbolts 18 as described above. Additionally, an erosion resistant coating 28 is

applied, via plasma spray techniques, to the combustion facing side of the FRCMC head/headliner to enhance endurance capabilities. Example: Fabrication of a FRCMC Headliner

1. Fabricate or purchase a headliner preform of the requisite size (there are a
5 number of U.S. vendors that weave composite preforms for composite applications) from fibers such as, but not limited to, alumina, Altex, Nextel 312, Nextel 440, Nextel 510, Nextel 550, silicon nitride, silicon carbide, HPZ, graphite, carbon, and peat. The preform should be made so that when loaded in the mold tool, it takes up between 30% and 70% of the open volume within the closed tool.
- 10 2. The preform then has a fiber interface coating applied to it as per industry best practices. The assignee of this application, Northrop Corporation, currently has a number of patents on the application of interface coatings, including, U.S. Patent No. 5,034,181, entitled APPARATUS FOR METHOD OF MANUFACTURING PREFORMS; U.S. Patent No. 5,110,771, entitled METHOD OF FORMING A PRECRACKED FIBER COATING
15 FOR TOUGHENING CERAMIC FIBER-MATRIX COMPOSITES; U.S. Patent No. 5,275,984, entitled FIBER COATING OF UNBONDED MULTI-LAYERS FOR TOUGHENING CERAMIC FIBER-MATRIX COMPOSITES; U.S. Patent No. 5,162,271, entitled METHOD OF FORMING A DUCTILE FIBER COATING FOR TOUGHENING NON-OXIDE CERAMIC MATRIX COMPOSITES; and U.S. Patent No. 5,221,578, entitled WEAK FRANGIBLE
20 FIBER COATING WITH UNFILLED PORES FOR TOUGHENING CERAMIC FIBER-MATRIX COMPOSITES, the teachings of which are incorporated herein by reference. Also, Allied Signal or Sinterials are commercial companies which will apply an interface coating as a purchased service.
3. The head-contoured preform is then placed in the headliner-shaped cavity
25 of a mold and the mold closed and sealed around it.
4. The lower feed holes in the mold are connected via flexible tubing with a valve to a container containing Blackglas resin. The upper vent hole is attached via flexible clear tubing with a valve to a vacuum source. Both valves are initially opened to

allow the resin to be sucked up through the mold.

5. The container with the Blackglas resin is pressurized above 15 PSI, i.e. above atmospheric pressure, to create a positive pressure tending to force the resin through the mold. When the resin is flowing through the mold with no air bubbles present in the tubing on the vacuum (exit) side, both valves are closed.

6. The mold with the enclosed preform and resin mixture is then heated as per the following cycle:

- A) Ramp from ambient to 150°F at 2.7°/minute
- B) Hold at 150°F for 30 minutes
- 10 C) Ramp at 1.7°/minute to 300°F
- D) Hold at 300°F for 60 minutes
- E) Cool at 1.2°/minute until temperature is below 140°F for part demolding.

It should be noted that there are a variety of heat-up cycle definitions which will create usable hardware and the foregoing is by way of one example only and not intended to be exclusive.

7. Upon cool-down of the mold, the mold is disassembled and the polymer composite component removed from the mold for pyrolysis.

NOTE: The previous seven steps identify a Resin Transfer Molding (RTM) approach to preparing the polymer composite component. Other applicable approaches to create the same part are Hand-Lay-up or Short Fiber Injection. These are all valid Polymer Composite Manufacturing Techniques to be included within the scope and spirit of the present invention and the claims appended hereto. These various techniques are not claimed to be inventive of the inventors herein in and of themselves.

8. The polymer composite component is then pyrolyzed. In this regard, fabrication of a sealable container, such as a stainless steel box, capable of withstanding 1900°F is required for the pyrolysis cycle in a standard furnace. In the alternative, an inert gas furnace could be used if available. The box should have two tubing connections, one on the bottom and one on the top to allow the box to be flooded with

an inert gas. In this example, the sleeve is placed in the box, the box placed in a standard furnace, stainless steel tubing is connected to the lower connector on the box and to a supply of high purity argon. Any equivalent inert gas could, of course, be used. The argon is allowed to flow into the box, and out the top vent at a rate of 5-10 SCFH
5 for the entire heat cycle, thus assuring the sleeve is totally bathed in an inert environment. The furnace is closed and fired on the following basis:

- A) Ramp to 300°F at 223°/hour
- B) Ramp to 900°F at 43°/hour
- C) Ramp to 1400°F at 20°/hour
- 10 D) Ramp to 1600°F at 50°/hour
- E) Hold at 1600°F for 4 hours
- F) Ramp to 77°F at -1 '5°/hour

Again, there are a variety of heating schedules other than this one, given by way of example only, which will yield usable hardware.

- 15 9. Upon cooling, the headliner is removed from the furnace and box and submerged in a bath of Blackglas resin for enough time to allow all air to be removed from the headliner (typically 5 minutes or more). A vacuum infiltration may also be used for this step.

10. Steps 8 and 9 may be repeated, if desired, until the percentage of pores
20 formed in the resin by outgassing is minimized and the strength of the part is maximized (typically five times).

11. The headliner is now ready for pre-wear coating application machining. At this time and prior to the application of the wear coating, all holes (spark plug, valves etc.) are machined (commercial grade diamond cutting tools recommended). Upon the
25 completion of the machining processes, all sharp edges on the surface of the headliner are knocked down using diamond paper.

12. The headliner is placed in an oven for a time and temperature adequate to assure "burn off" of any of the cutting lubricants used in the machining process.

(Typically 2 hours @700°F, but is lubricant dependent)

13. The combustion chamber side of the headliner is grit-blasted using a grit and pressure adequate to remove any loose matrix material and expose the fibers within the FRCMC. (Typically 100 grit @ 20 PSI).

5 14. The headliner is cleaned by using clean dry compressed air.

15. The headliner is then loaded in a holding fixture for the plasma spray process.

16. Direct air blowers are used to cool the non-combustion chamber side of the headliner.

10 17. The plasma sprayed wear coating is then applied using a deposition rate set to 5 grams per minute or more. The holding fixture rotational speed, plasma gun movement rate across the surface, and spray width are set to achieve a barber pole spray pattern with 50% overlap. The spray gun is set relative to the sprayed surface from 0.1 inches to 3 inches away. Particle sizes used for this process range from 170
15 to 400 mesh. Enough material is applied to allow for finish machining.

18. After the application of the wear coating, the headliner combustion chamber area is smoothed out with diamond paper or an appropriate form tool (commercial grade diamond tools recommended) to achieve the final inner contour.

19. The headliner can then be bonded to or cast within it's metallic mate as
20 appropriate to the particular embodiment being implemented. After installation with it's mate, the block-mating surface of the headliner is machined flat. In the case of the embodiment of Figure 7, the headliner is machined flat separately since it is not physically attached to the metal head and water jacket.

WHAT IS CLAIMED IS:

1. A ceramic cylinder head for an internal combustion engine comprising:
 - a) a cylinder head comprised of a generic fiber system having disposed
5 throughout a pre-ceramic polymer resin in its ceramic state where said pre-ceramic polymer resin consists of a polymer-derived ceramic resin; and,
 - b) means for transferring heat away from a top surface of the cylinder head to maintain the cylinder head below a threshold temperature.
- 10 2. The ceramic cylinder head of claim 1 wherein said means for transferring heat away from a top surface of the cylinder head comprises:
radiating fins formed in said top surface of the cylinder head for transferring heat to air surrounding said fins.
- 15 3. The ceramic cylinder head of claim 1 wherein said means for transferring heat from a top surface of the cylinder head comprises:
a metal heat sink attached to said top surface, said heat sink including radiating fins for transferring heat to air surrounding said fins.
- 20 4. The ceramic cylinder head of claim 1 wherein said means for transferring heat from a top surface of the cylinder head comprises:
a metal water jacket formed onto said top surface, said water jacket having an inlet pipe and an outlet pipe for passing engine coolant therethrough.
- 25 5. The ceramic cylinder head of claim 1 wherein said means for transferring heat from a top surface of the cylinder head comprises:
a metal water jacket adhesively bonded or mechanically attached onto said top surface, said water jacket having an inlet pipe and an outlet pipe for passing engine



coolant therethrough.

6. The ceramic cylinder head of claim 1 wherein:
said means for transferring heat from a top surface of the cylinder head
5 includes means for heating a fluid used in a passenger compartment heating system.

7. The ceramic cylinder head of claim 1 and additionally comprising:
an erosion-resistant coating disposed over a combustion facing side of said
cylinder head whereby endurance capabilities of the cylinder head are enhanced.

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8. A ceramic cylinder head for an internal combustion engine comprising:
a) a cylinder head made of a generic fiber system having disposed
throughout a pre-ceramic polymer resin in its ceramic state where said pre-ceramic
polymer resin consists of a polymer-derived ceramic resin; and,
15 b) a metal water jacket formed onto a top surface of said cylinder head,
said water jacket having an inlet pipe and an outlet pipe for passing engine coolant
therethrough to maintain the cylinder head below a threshold temperature.

9. The ceramic cylinder head of claim 8 and additionally comprising:
20 an erosion-resistant coating disposed over a combustion facing side of said
cylinder head whereby endurance capabilities of the cylinder head are enhanced.

10. A ceramic cylinder head for an internal combustion engine comprising:
a) a cylinder head made of a generic fiber system having disposed
25 throughout a pre-ceramic polymer resin in its ceramic state where said pre-ceramic
polymer resin consists of a polymer-derived ceramic resin; and,
b) a metal water jacket adhesively bonded or mechanically attached to
a top surface of said cylinder head, said water jacket having an inlet pipe and an outlet



pipe for passing engine coolant therethrough to maintain the cylinder head below a threshold temperature.

11. The ceramic cylinder head of claim 10 and additionally comprising:
5 an erosion-resistant coating disposed over a combustion facing side of said cylinder head whereby endurance capabilities of the cylinder head are enhanced.

12. A ceramic lined cylinder head for an internal combustion engine comprising:
a) a cylinder liner head liner having a combustion facing side and being
10 of a generic fiber system having disposed throughout a pre-ceramic polymer resin in its ceramic state where said pre-ceramic polymer resin consists of a polymer-derived ceramic resin; and,
b) a metal cylinder head disposed over a top surface of said cylinder head liner, said metal cylinder head including means for transferring heat away from said
15 top surface of said cylinder head liner to maintain the cylinder head below a threshold temperature.

13. The ceramic lined cylinder head of claim 12 wherein said means for transferring heat away from said top surface of said cylinder head liner comprises:
20 radiating fins formed in a top surface of said metal cylinder head for transferring heat to air surrounding said fins.

14. The ceramic lined cylinder head of claim 12 wherein said means for transferring heat away from said top surface of said cylinder head liner comprises:
25 a metal heat sink attached to a top surface of said metal cylinder head, said metal heat sink including radiating fins for transferring heat to air surrounding said fins.



15. The ceramic lined cylinder head of claim 12 wherein said means for transferring heat away from said top surface of said cylinder head liner comprises:

a metal water jacket formed into said metal cylinder head, said water jacket having an inlet pipe and an outlet pipe for passing engine coolant therethrough.

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16. The ceramic lined cylinder head of claim 12 wherein:

said means for transferring heat away from said top surface of said cylinder head liner includes means for heating a fluid used in a passenger compartment heating system.

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17. The ceramic lined cylinder head of claim 12 and additionally comprising:

an erosion-resistant coating disposed over said combustion facing side of said cylinder head liner whereby endurance capabilities of the cylinder head liner are enhanced.

