Sept. 24, 1968 E. J. GEIGER ET AL 3,402,644

INTERNAL COMBUSTION ENGINE PISTON WITH PRESTRESSED INSERT

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FIG. 1.

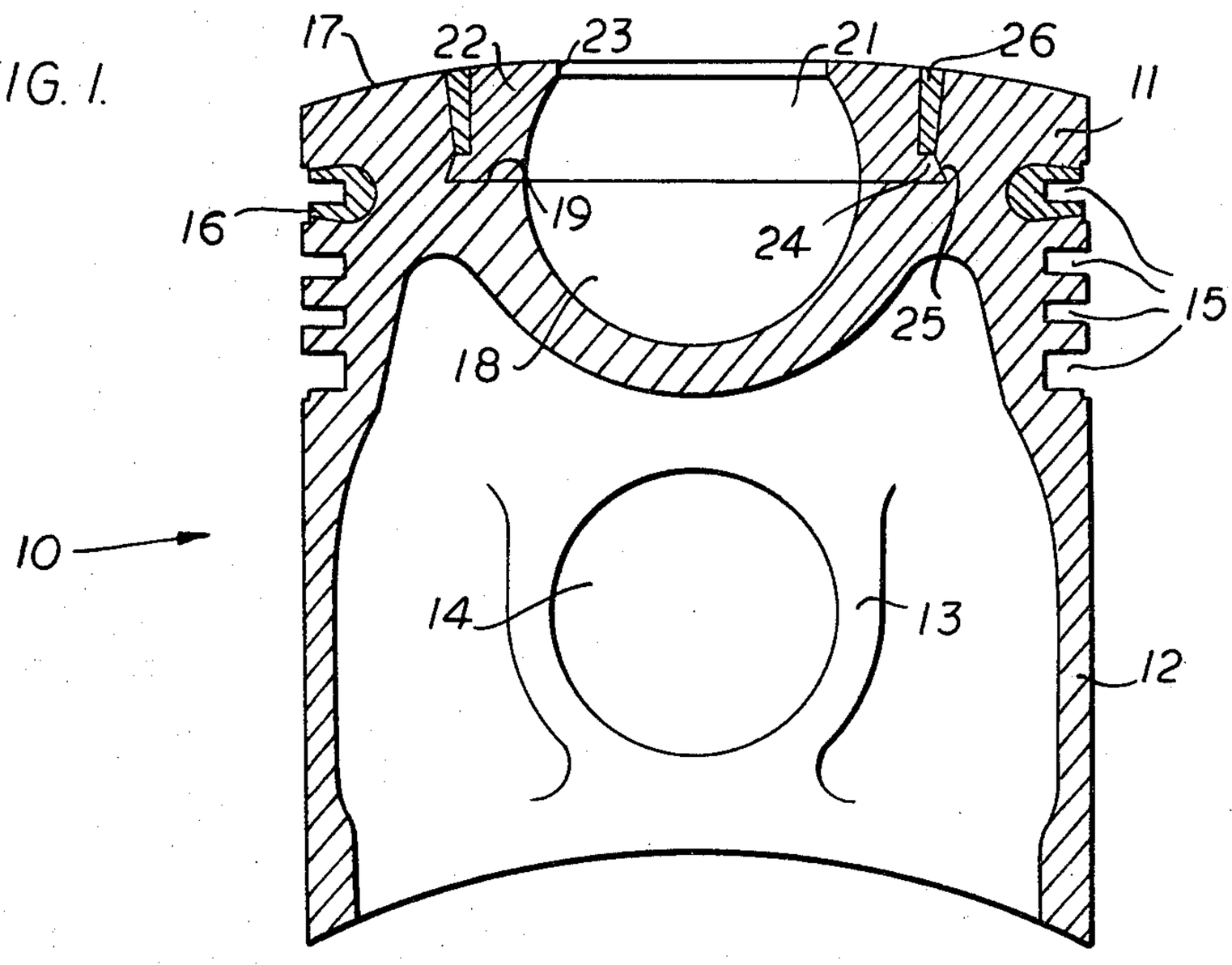



FIG. 2.

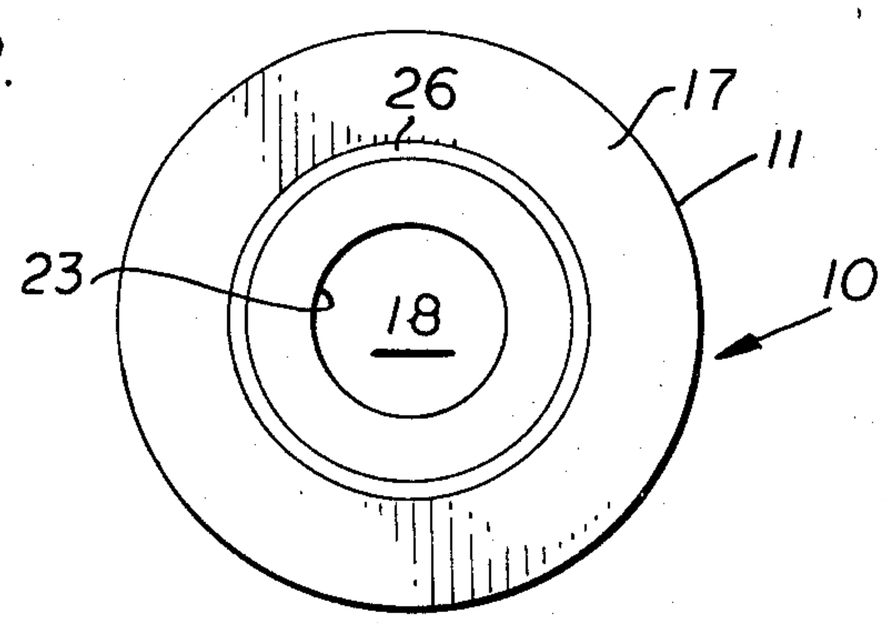
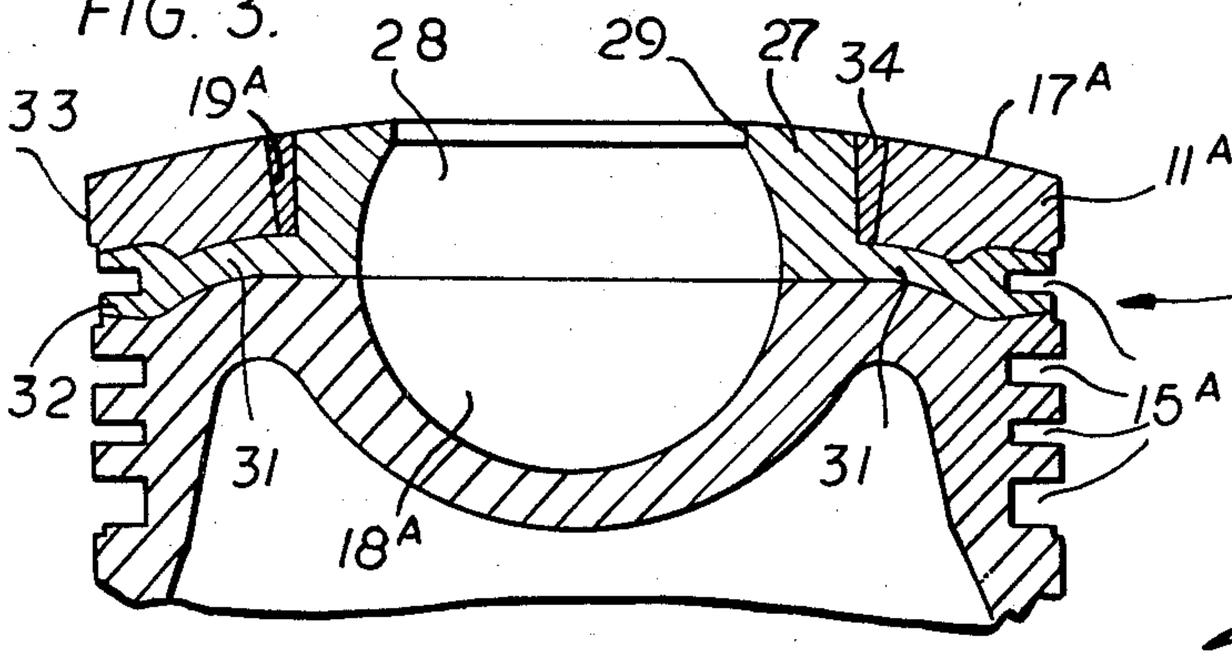



FIG. 3.




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# INTERNAL COMBUSTION ENGINE PISTON WITH PRESTRESSED INSERT

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## ABSTRACT OF THE DISCLOSURE

An internal combustion engine piston construction of the open chamber type wherein a combustion chamber cavity is provided in the head of the piston which cavity opens to the piston face and is partially defined by an annular insert at the combustion chamber opening. The annular insert is prestressed in compression by means of an annular ring encircling the same and the coefficient of expansion of the material of which the annular ring is made is greater than the coefficient expansion of the material of which the annular insert is made and is also equal to or less than the coefficient of expansion of the material of which the piston body proper is made.

The present invention relates to a piston utilized in internal combustion engines and, more particularly, to a piston of the open chamber type having an insert therein at the face of the piston and partially defining the combustion chamber, the insert being prestressed to overcome the stresses induced therein during use.

Internal combustion engine pistons are subjected to unusual stress systems and unique environmental conditions in use. Since the stress system is affected by thermal gradients and heat load cyclic conditions, the overall system becomes very complex. In certain types of piston designs such as open chamber pistons wherein a combustion chamber is formed in the piston head, thin lips and complex geometrical configurations contribute to the stress field and spectrum complexity. Mechanisms of piston cracking may be affected by piston materials property in regard to elevated temperature fatigue, thermal shock, thermal stress fatigue and thermal fatigue. The present invention relates to an insert ring for the piston of the open chamber type and the method of piston formation to overcome the problem of piston cracking where the piston has relatively thin lip areas subject to high stresses.

In order to fully appreciate the merits and novelty of the piston construction and method of making the same which form the basis of the present invention, it is thought necessary to briefly review the mechanism by which material failures may occur in piston designs presently being used. The present invention is primarily concerned with the elimination of the type of failure commonly referred to or called "thermal cracking." As pointed out hereinbefore, this terminology is somewhat naive as the conditions causing cracking may be quite complex. When material separation occurs, it is due obviously to stresses of a given nature being greater than the strengths of the same variety. In internal combustion engine pistons of the open chamber type wherein a cavity is provided in the head of the piston which cavity opens into the piston face, the fractures in the piston face invariably emanate from the relatively thin lip defining the chamber opening and extends radially outwardly on the face of the piston. It has been found that when a stress is anticipated in a given direction in a member, a preload stress applied to the member which is opposite in sign to the anticipated stress will result in an increase in durability of the member. Hence, before the problem can be solved by utilizing



this principle and by incorporating a counteracting stress system in the piston, it is necessary to know the nature and application of the stresses generated in the piston when in use. In this regard it is thought that at least the following stress generating systems are possible.

### (1) *Static thermal gradients*

Any part which is subjected to a heat source on one side and a coolant on the other has generated in it a thermal gradient. If this gradient is steep enough stresses of significant magnitude can be developed. Under steady strain conditions the significant characteristics of the materials to resist crack formation are stress-rupture and creep characteristics. This condition is not particularly significant in diesel pistons; however, the principles involved in the present invention might well be applicable and of importance in other applications.

### (2) *Dynamic thermal gradients*

When a thermal gradient is caused to change by modification of the heat and cooling systems, cyclic stresses are induced.

(a) As an example, if a particular part of cylindrical shape is brought to a given elevated temperature and allowed to become uniform throughout, then subsequently quenched so that the surface is brought down in temperature rapidly in relation to the interior, transient circumferential tensile stress is generated at the part surface and a balancing compressive stress in the interior.

(b) In reverse, when a part of cylindrical cross section is heated very rapidly from the essentially cold condition a reverse themal gradient is imposed and compressive circumferential surface stresses are generated which are balanced by tensile stresses in the interior.

When either the above described thermal-cycles are repeated a large number of cycles and the elastic strains generated are of a sufficient magnitude, thermally induced stress fatigue, referred to above as thermal stress fatigue, will result.

### (3) *Cyclic plastic strain*

When the thermal gradients described in No. 2 above are severe enough to cause appreciable permanent set in the part in a single thermal stress cycle failure will occur in a short number of cycles and possibly even one. This is referred to above as thermal shock. From the foregoing it is believed understandable that the properties of materials used for making pistons, such as coefficient of conductivity, coefficient of expansion, hot strength and elastic modulus are important when thermal cycling of the piston is involved.

With the possibility of the aforementioned stress systems being generated in the piston under elevated temperature conditions as might be present in a diesel engine piston used in a motor vehicle, the present invention contemplates the substantial elimination of the effectiveness of such stress-generating systems to adversely influence the durability and operating life of the piston.

Among the objects of the present invention is the provision of an open chamber type piston for an internal combustion engine having an annular insert forming the thin lip area or critical area of high stress concentration which insert is prestressed in a particular manner to increase the durability of the piston under normal operating conditions. In addition to the thermally-induced stresses, the piston is also subjected to stresses caused by the explosions in the combustion chamber during operation of the engine. It has been found that when a stress is anticipated in a given direction in a member, a preload stress applied to the member which is opposite in sign to the anticipated stress will result in an increase

in durability of the member. The latter stresses imparted to the lip area by the combustion explosion forces in an open chamber type piston are generally circumferential and tensile in nature and, therefore, the insert for the piston is prestressed in compression a direction opposite the stresses caused by such combustion explosions to increase the durability of the piston.

Another object of the present invention is the provision of a piston of the open chamber type having a novel insert defining the upper portion of the combustion chamber and forming the annular lip of the chamber at the upper face of the piston. The insert is formed of the requisite size and shape and then a compression ring of a high strength of material is shrunk onto the insert. Both the insert and the high strength material ring would normally be annular in configuration. After the insert has the preload stress applied thereto, the main piston body is cast around the insert and stressing ring.

A further object of the present invention is the provision of a piston of an open chamber type having a generally spherical chamber in the face of the piston in which combustion primarily occurs, an annular insert of a suitable high strength of material defining the chamber, and a compression ring which is heat shrunk onto the annular insert to provide a preload stress. The insert also forms the inwardly extending upper lip of the chamber at the intersection of the chamber with the face of the piston. By matching the materials of which the piston proper, annular insert and compression ring are made as far as the coefficients of expansion of such materials in a novel manner, the thermally induced stresses can be reduced to a tolerable level. It is therefore, another important object of the present invention to provide an internal combustion engine piston design constructed of the aforementioned parts in which the material of each of such parts is selected in a novel manner with regard to the coefficient of expansion of such part and in relation to the coefficients of expansion of the other piston parts so as to accommodate a given thermally induced stress system in the piston. It is well known, the coefficients of expansion of materials of mating parts affect the stress level induced on such mating parts and interfaces. In general, the lower the coefficient of expansion the better; however, given one of the aforementioned piston parts made of a material with a particular coefficient of expansion, ideally, taking into consideration the gross temperature gradients caused by variations in thermal conductivity, the coefficients of expansion of the other piston parts of the present piston design may be matched to cause very little relative movement and, consequently, to avoid the generation of high stresses.

The present invention also comprehends the provision of a novel method and manner of forming an open chamber type piston by first forming an insert, exerting a preload stress on the insert and then casting the piston body about the insert whereby a portion of the finished piston is prestressed in use.

The foregoing objects and desirable features inherent in and encompassed by the invention, together with many of the purposes and uses thereof, will become readily apparent from a reading of the ensuing description in conjunction with the annexed drawings, in which:

FIGURE 1 is a vertical cross-sectional view through a piston of the open chamber type having a prestressed insert therein forming the entrance opening of the chamber in the face of the piston;

FIGURE 2 is a top plan view of the piston of FIGURE 1 on a reduced scale; and

FIGURE 3 is a vertical cross sectional view of an open chamber type piston having a second embodiment of prestressed insert therein.

Referring to the drawings in detail, wherein like reference characters represent like elements throughout the various views, there is shown illustrative embodiments of the present invention. FIGURES 1 and 2 disclose a



piston **10** of the open chamber type for use in an internal combustion engine, such as a diesel engine, with the piston preferably being formed of a relatively light weight metal, such as aluminum or an aluminum alloy. The piston includes a head **11** and a depending skirt portion **12** containing wrist pin bosses **13** which define wrist pin openings **14** as is conventional in piston design.

Formed in the exterior circumference of the head **11** are a plurality of circumferential grooves **15** adapted to receive piston rings for the sealing of the piston within a cylinder; the uppermost groove **15** being formed in an annular ring **16** of a high strength metal, such as a ferrous alloy, where wear on the piston ring grooves is greatest and the seating of the first piston ring is of importance in preventing compression leakage. The face **17** of the piston head **11** is formed with a central hemispherical chamber **18** and an annular undercut groove **19**.

The upper portion **21** of the chamber is formed within a generally annular insert **22** positioned in the groove **19**. The insert **22** is formed of a suitable high strength material, such as a ferrous alloy of the Ni-Resist type or it may be made of gray cast iron. Preferably the material should have a high coefficient of thermal conductivity to enhance its ability to dissipate heat and thus substantially reduce the magnitude of local hot spots and the nominal temperature at which the piston operates. The material also should have a relatively high resistance to yield, creep-rupture and fatigue at elevated temperatures. The insert **22** provides an annular internal lip **23** defining the entrance to the chamber and an external and outwardly extending lower lip or flange **24** defining an annular groove or channel thereabove. An annular ring **26** of a material having high strength at normal as well as operating temperatures of the piston and good resistance to tempering is positioned in the channel or groove formed above the flange **24** and surrounds the insert **22**. Preferably, the annular ring **26** is made of austenitic or martensitic stainless steel alloys or Ni-Resist type alloys having tailored coefficients of expansion. The flange **24** has parallel sides and an annularly disposed or inclined outer edge **24** forming an undercut portion for the undercut groove **19** of the piston head **11**. From the aforementioned list of preferable materials of which to make the piston proper, insert **22** and ring **26**, it will be appreciated that the ring **26** is made from a material having a coefficient of expansion equal to or greater than the coefficient of expansion of the piston material proper and greater than the coefficient of expansion of the insert material.

Through experimentation and knowledge gained through experience and as pointed out herebefore, indications have shown that when a stress in a given direction is anticipated, a preload stress opposite in sign applied to the system will result in an increase in durability. Here, the lip area **23** of the chamber **18, 21** of the piston **10** because of its geometric configuration and location will be exposed to higher stresses during the operation of the internal combustion engine than any other area or part of the piston. As pointed out hereinbefore, the lip area **23** is subjected to radially outwardly directed pressures caused by the combustion explosions which pressures result in circumferential tensile stresses being generated in the lip area **23**. Therefore, in accordance with the invention, the insert **22** is prestressed in compression prior to assembly in the piston **10** by the annular ring **26** to counteract such outwardly directed forces caused by the explosions in the combustion chamber applied on the combustion chamber wall and the induced tensile stresses in the lip area **23** occasioned thereby. It will also be appreciated that the thermally-induced stresses in the area of the annular lip **23** generated when the face of a hot piston when suddenly cooled are circumferential and tensile in nature as pointed out above.

It should also be pointed out that as far as the many factors adversely influencing piston operating life are con-

cerned, the thermally-induced stress system is, by far, more critical and significant than the pressure-induced stress system caused by combustion explosions. Thus, more importantly, the fact that the insert **22** is prestressed in compression such thermally-induced stresses are also counteracted by the prestress system incorporated into the insert **22**.

In addition to the prestress system embodied in the piston design of the present invention, additional means are provided for enhancing the life of the piston. The fact that the annular ring **26**, insert **22** and the body of the piston are made of different materials which materials have, as stated hereinbefore, different coefficients of expansion the deleterious effect of the thermally-induced stress system is substantially mitigated as will be pointed out presently. As an example, at wide open throttle, full load engine operating conditions, the piston top temperature is essentially uniform and at a maximum. If the operating conditions are changed, say by reducing the load on the engine as might occur if the engine containing the piston was utilized to propel a motor vehicle and the motor vehicle should crest the top of a steep grade and begin to coast on the other side. When this occurs, essentially cold air is drawn into the cylinders and the piston top is quenched by the ingested cold air. Under these circumstances, a temperature gradient is produced which can be described by saying that the top surface of the piston is cold being in contact with the coolant (cold air), while the interior mass or mass beneath the piston top is still substantially hot. This is obviously a transient condition. It can be reasoned though that a significant tensile stress can be generated under these conditions in the surface of the piston in direct contact with the cold air. The colder surface material attempting to contract around the hotter interior material will be in tension and the interior in balancing compression. Consequently, in those prior piston designs wherein the insert **22** and annular ring **26** do not exist and such insert and ring are in effect, integrally formed with and of the same material as the piston body, radially extending cracks emanating from the thin lip **23** at the entrance of the combustion chamber oftentimes developed in the top surface or face **17** of the piston head **11**. With the piston construction described above and embodying the invention, the annular ring **26** is made of material that has a coefficient of expansion greater than the coefficient of expansion of the material of which the piston head **11** is made. Consequently, in the example given above wherein the piston face **17** is suddenly quenched by injecting cold air into the engine cylinder and a temperature gradient is produced in the piston, detrimental tensile stresses are generated in the "quenched" surfaces of the piston which "quenched" surfaces include the portion of the piston face **17** disposed radially outwardly of the annular ring **26**, and the exposed surfaces of the annular ring **26** and the annular insert **22**. Inasmuch as the coefficient of expansion of the piston body material is equal to or less than the coefficient of the expansion of the annular ring **26**, the material of which is deliberately selected to have a coefficient of expansion equal to or greater than the coefficient of expansion of the piston body material, the surface portion of the piston face **17** radially outwardly from the annular ring **26** reacts to a lesser degree than the exposed surface of the annular ring **26** to the same or such temperature gradient. Thus, as the aluminum or aluminum alloy surface portion of the piston face **17** radially outwardly from the annular ring **26** attempts to contract in the above operating condition used as an example tending to set up detrimental circumferential tensile stresses, the annular ring **26**, being made of a material having a relatively greater coefficient of expansion, will have a higher rate of contraction and, thus such contraction of the aforementioned annular portion of the piston face **17** has very little effect, if any, on the stress condition present in the area of the lip **23** or the critical area where failure is



most likely to occur. In effect, the annular insert **22** and, in particular the critical high stress concentration area of the lip **23** of such insert **22**, is isolated from influence of the tensile stresses thermally-induced in the annular portion of the piston face **17** disposed radially outwardly of the annular ring **26**. As pointed out hereinbefore, while tensile stress would be present at the piston top surface in general during the aforementioned engine operating conditions, it is somewhat aggravated and concentrated at the piston lip **23**. It has been established that the lip **23** constitutes the critical area as far as failure is concerned, and, consequently, the present invention is primarily concerned with the provision of a counteracting stress at this location during the "down transient" operating condition described above. It will also be appreciated that inasmuch as the coefficient of expansion of the annular ring **26** is greater than the coefficient of expansion of the insert **22** material, the surface portion of the insert **22** radially inwardly from the annular ring **26** will, accordingly, react to a lesser degree than the exposed surface of the annular ring **26** to such temperature gradient. Thus, the annular ring **26** will contract more rapidly than the internal lip **23** and a compression stress will be generated and since such compression stress generation is occurring at the time the "down transient" is generating a tensile stress, the compressive stress will tend to negate the detrimental tensile stress in the lip **23**. from the foregoing, it will be appreciated by prestressing the annular insert **22** in compression and by making the annular ring **26** of material having a coefficient of expansion larger than the coefficient of expansion of the material of which the piston proper is made, the thermally-induced stresses as well as the stresses resulting from combustion explosions on the exposed surface of the annular insert **22** and especially the critical high stress concentration area of the annular internal lip **23** are reduced to a tolerable level. It therefore follows that the durability and operating life of the piston is increased tremendously. It is to be understood that a wide variety of materials are available to be utilized for constructing the piston body proper, the annular ring **26** and the annular insert **22**. It is merely necessary to select the materials bearing in mind the aforementioned properties required of each of the materials and parts in order to achieve the very desirable prestress and operating stress system in the piston.

In the construction of the piston, ring **26** is heat shrunk onto the insert **22** causing an inwardly directed compressive stress to be imparted to the insert **22**. The piston **10** is then cast around this compression ring **26** and prestressed insert **22** with the flange **24** of the insert **22** forming an interlock with the piston in the groove **19**. The insert-to-ring interface, insert-to-piston material interface, and ring-to-piston-material interface are all suitably treated in such a manner as to improve metallurgical bonding therebetween and improve heat flow at the junctures. Obviously, the annular ring **16** is properly located in the mold relative to the compression ring **26** and insert **22** prior to casting the piston **10**.

After casting, the piston **10** is machined to the accurate size required as shown in FIGURE 1 and the grooves **15** are machined into the piston head **11** and the annular ring **16**. Once the piston rings (not shown) are inserted into the grooves **15**, the piston is then ready for use. In view of the preload stress on the insert **22**, the lip **23** at the entrance to the chamber **18, 21** will show substantially improved resistance to cracking and increased durability during use.

A second embodiment of insert in a piston **10***a* is shown in FIGURE 3, the piston having a piston head **11***a* with a face **17***a*, the piston formed with a hemispherical chamber **18***a* and the head with a groove **19***a*. An insert **27** having a chamber portion **28** therein, and defining an internal lip **29** for the chamber is positioned in the groove **19***a*. The insert is provided with a plurality of radial arms **31** integral therewith and integral with an annular

ring **32** incorporated within the exterior surface **33** of the piston head **11***a*. A compression ring **34** is heat shrunk onto the outer surface of the insert **27** prior to casting of the piston **10***a* to create a prestress in the insert. Then the insert **27** and integral annular ring **32** and the compression ring **34**, previously shrunk onto the insert, are positioned in a suitable mold, and the piston material is injected therein to encompass and flow around the annular ring **32** and radial arms **31** and surround the insert **27** and compression ring **34**. The piston surface is then machined and the piston ring grooves **15***a* are machined in the piston head **11***a* and in the annular ring **32**.

Although the use of a prestressed insert and of piston parts of various coefficients of expansion have been disclosed herein for use in a piston of the open chamber type, the prestressed opening and matched coefficients of expansion approach could also be applied to inserts for precup constructions or the like, and it is not our desire or intent to unnecessarily limit the scope or utility of the improved features by virtue of these illustrative embodiments.

The embodiments chosen for the purposes of illustration and description therein are those preferred for achieving the objects of the invention and developing the utility thereof in the most desirable manner, due regard being had to existing factors of economy, simplicity of design and construction, and the improvements sought to be effected. It will be appreciated, therefore, that the particular structural and functional aspects emphasized herein are not intended to exclude, but rather to suggest such other adaptations and modifications of the invention as fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

**1.** A piston for an internal combustion engine comprising a piston head provided with a normally top surface and having an annular internal recess and a depending skirt, an annular ring-like insert in the recess of said head, a surface portion partially defining said recess in said piston head and said insert defining an internal chamber, said insert being provided with a radially inwardly extending lip at one end defining an outer opening of the chamber adjacent a plane containing the top surface of said piston head, and means prestressing said insert in compression.

**2.** A piston for an internal combustion engine as set forth in claim **1**, wherein said means prestressing said insert in compression includes an annular ring encircling and engaging an annular surface portion of said insert.

**3.** A piston for an internal combustion engine as set forth in claim **2**, wherein the coefficient of expansion of the material of which said annular ring is made is greater than the coefficient of expansion of the material of which said piston head is made.

**4.** A piston for an internal combustion engine as set forth in claim **2**, wherein the coefficient of expansion of the material of which said annular ring is made is greater than the coefficient of expansion of the material of which said insert is made.

**5.** A piston as set forth in claim **4**, including a second annular ring in the exterior surface of the piston, said ring having an annular groove therein receiving a piston ring.

**6.** A piston as set forth in claim **3**, including means interlocking the piston head and insert together.

**7.** A piston as set forth in claim **6**, in which said interlocking means includes a second lip at the normally lower end of the insert extending radially outwardly beyond said first mentioned annular ring, said second lip having an angularly disposed outer surface for interlocking engagement with a complementary surface in the piston head.

**8.** A piston as set forth in claim **6**, in which said interlocking means includes plural radial arms integral with the insert, and a second annular ring integral with said arms and located at the outer circumference of the piston.

**9.** A piston as set forth in claim **8**, in which said annular ring in the outer circumference of the piston has a piston ringe groove formed therein.

**10.** A piston for an internal combustion engine as set forth in claim **3**, wherein the coefficient of expansion of the material of which said annular ring is made is greater than the coefficient of expansion of the material of which said insert is made.

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