ARTICLE OF BONDED FERROUS METAL AND ALUMINUM

Filed Nov. 20, 1961 3 Sheets-Sheet 1

FIG. 1

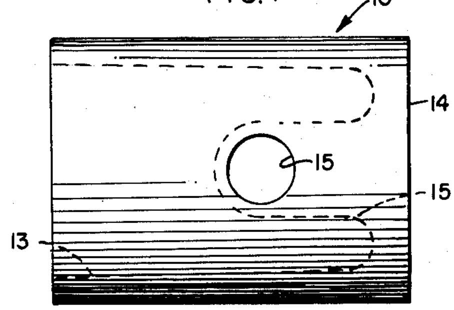


FIG. 2

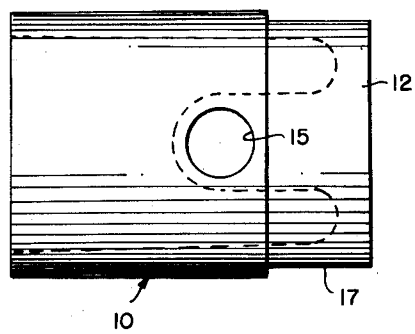


FIG. 3

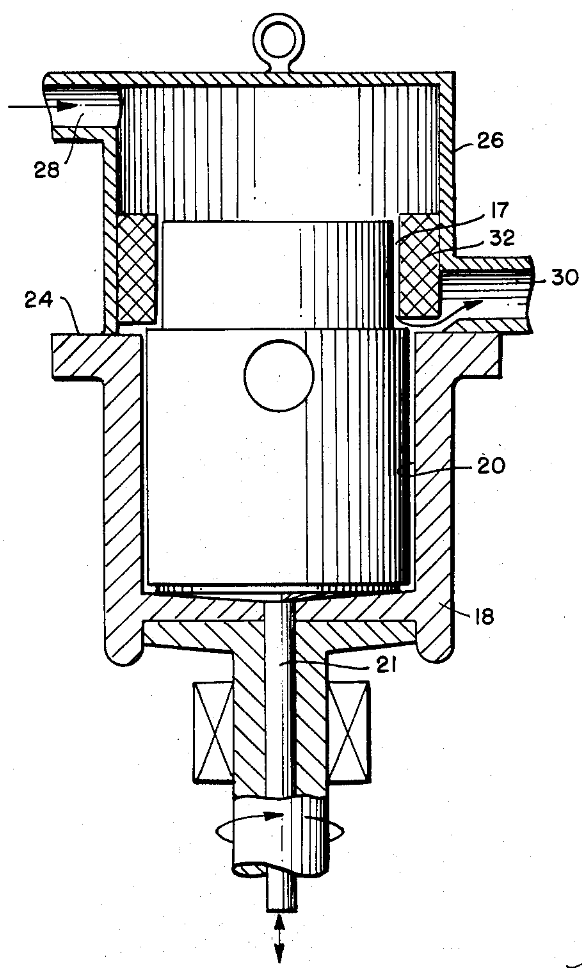
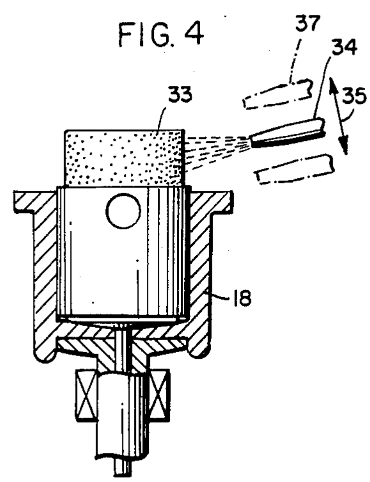


FIG. 4



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Aug. 31, 1965 C. G. A. ROSEN **3,203,321**

ARTICLE OF BONDED FERROUS METAL AND ALUMINUM

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FIG. 5

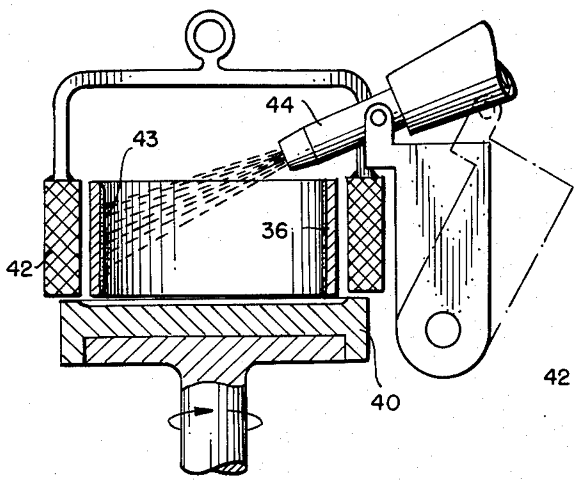


FIG. 6

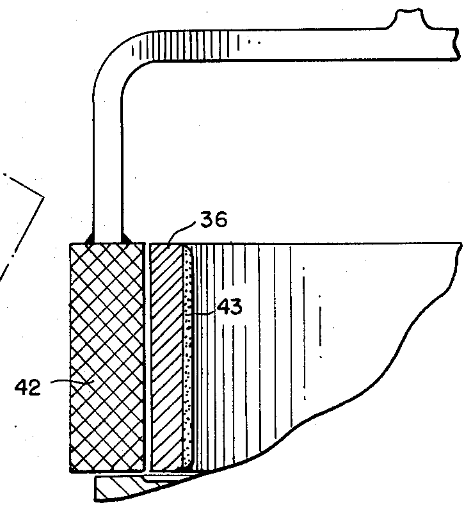


FIG. 7

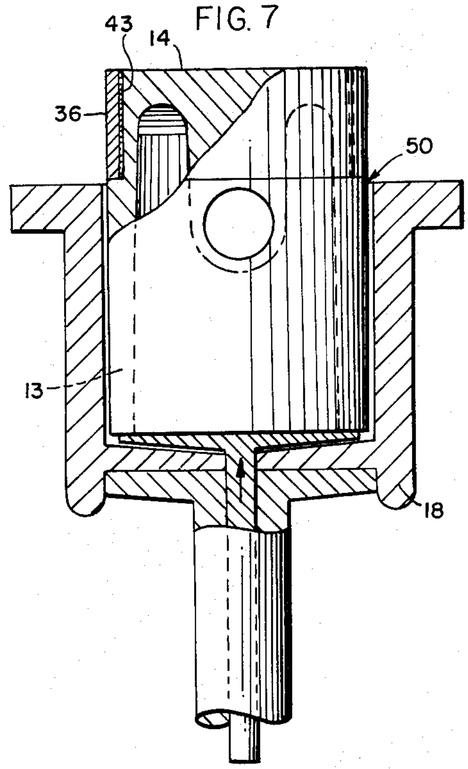
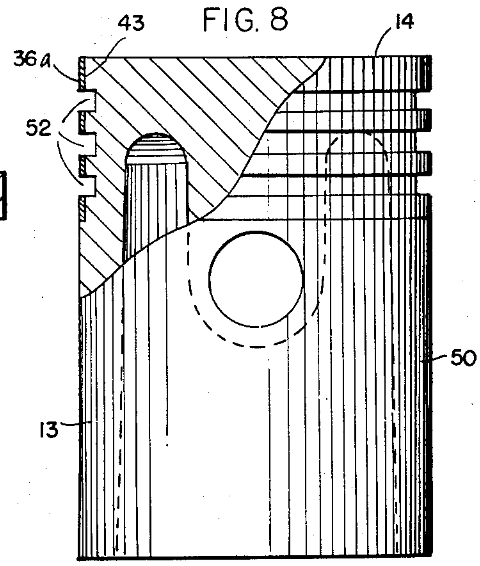


FIG. 8



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ARTICLE OF BONDED FERROUS METAL AND ALUMINUM

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FIG. 9

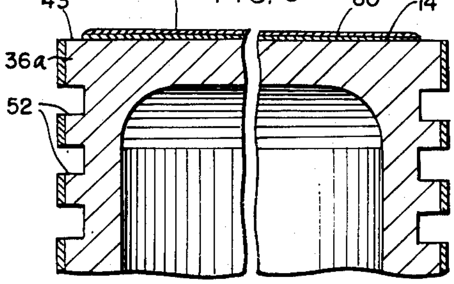


FIG. 10

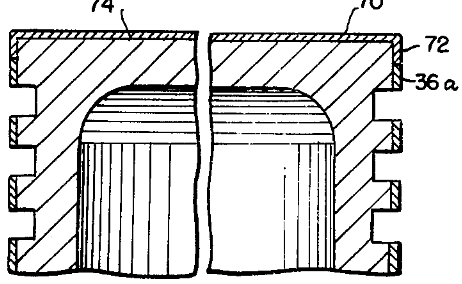


FIG. 11

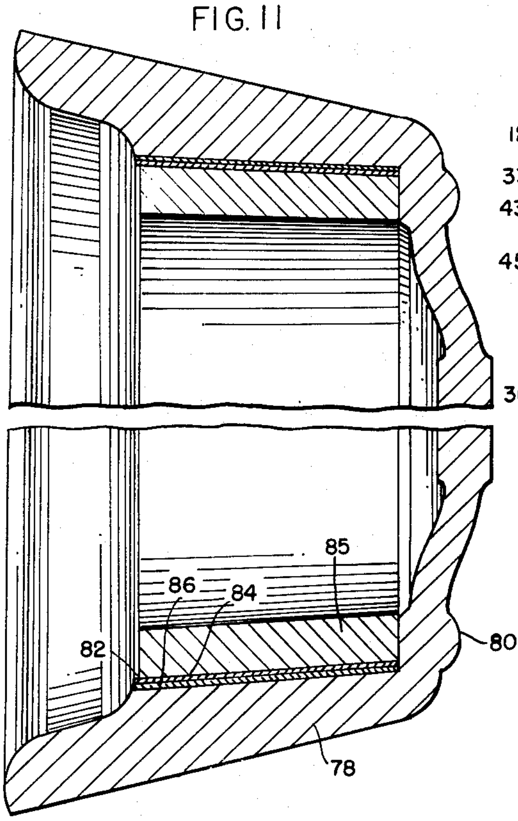
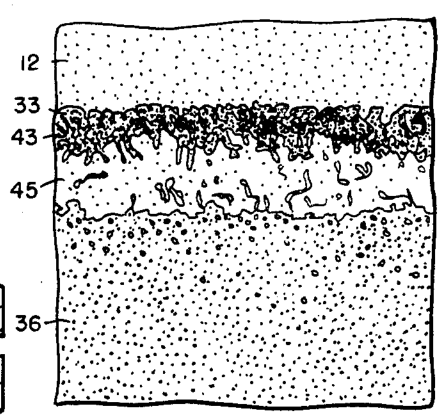


FIG. 12



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3,203,321

Patented Aug. 31, 1965

3,203,321

ARTICLE OF BONDED FERROUS METAL AND ALUMINUM

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Filed Nov. 20, 1961, Ser. No. 153,483
6 Claims. (Cl. 92—223)

This is a continuation-in-part of Patent No. 3,041,116 which is a division of Patent No. 3,041,194 filed February 1, 1955 in which a method, apparatus and article have been disclosed by which the margins of a groove or shoulder in an aluminum member are reinforced by rings of flame sprayed hard metal including stainless steel. Other patents owned by the same assignee are the Dailey et al. patents, Nos. 2,833,264; 2,833, 603 and 2,833,668 issued May 6, 1958.

This invention relates to an improved method of fusing a preformed ferrous metal member to a preformed aluminum body and to various products formed thereby.

The term "aluminum" as used herein encompasses aluminum and aluminum base alloys which contains at least 50% by weight of aluminum and the term ferrous metal includes iron and alloys thereof including steel and particularly stainless steel.

In these earlier inventions for reinforcing aluminum members, layers of hard metal such as stainless steel are flame sprayed on a prepared aluminum surface. This metallizing step consumes time which is desirable to save if mass production is contemplated at low cost. Even when the layer of sprayed ferrous metal is as thin as $\frac{1}{32}$″ the time required is an important competitive consideration.

In the present invention it is possible to ultilize a preformed band or cup of ferrous metal. Such is bonded to a preformed body in a novel way that is rapid and produces an article that can be quickly and easily machined with conventional production equipment, yet preserves all the strength, protection, and other benefits attained by the metallization of preformed aluminum bodies just mentioned. The novel method and product contemplates a preformed ferrous member and a preformed aluminum member preferably treated rapidly and simultaneously in timed relationship as described herein, so that they may brought together under predetermined conditions to form a permanently integrated unitary body.

By way of example, for purposes of a better understanding of the benefits of the invention, the present invention is described herein mainly in connection with a forged aluminum body such as an internal combustion engine piston. It is known that outwardly expanding rings of a comparatively hard metal are installed in circumferential grooves cut in the outer surface of pistons to slide and seal against the cylinder walls in internal combustion engines. The first one or two rings near the head of the piston are generally referred to as compression rings and serve to block the escape there-past of flame and hot gases developed during the compression and explosion strokes, whereas the rings further down towards the skirt of the piston are oil rings which check the passage of lubricant past the piston during its reciprocation.

Due to the intense heat to which the head of such a piston is subjected, the aluminum stock around the compression ring tends to soften enough that between the friction with the cylinder wall resisting reciprocating movement of the compression ring and the inertia of the ring itself resisting reversal of its direction of movement under rapid reciprocation of the piston, the harder metal of the piston ring "hammers" against the soft aluminum

stock forming the sides of its groove and enlarges the groove. This hammering is further augmented by the gas pressure dynamics acting on the underside of the top ring with a force superior to inertia forces present which causes a ring flutter each expansion stroke. The hammering condition becomes worse and worse as the groove becomes wider and wider.

In the present invention the piston is provided with a preformed steel band over a piston ring groove area, which band, when the ring grooves are cut therethrough, provides hard metal margins for the ring grooves reinforcing the ring grooves against ring hammer, ring cooling and other deteriorating conditions well understood in the art.

The band receving area of the piston is turned down to a diameter which allows a shrinking of the band thereon. It can be approximately the inside diameter of the band or a little larger at room temperature. Then the surface of the turned down portion is preferably deoxidized or stripped to expose unoxidized metal. This can be done with a chlorine atmosphere at a temperature around 900° F. and thereafter the area is immediately sprayed with a mono-molecular layer of a metal whose melting point is preferably above the boiling point of the aluminum. Although as described in said earlier patents, sprayed molybdenum can accomplish unoxidized metal-to-metal contact between molybdenum and aluminum, the stripping of part or all of the oxidized aluminum surface is an aid for production speed and quality control and can be accomplished while the piston is differentially hot enough to provide beneficial molecular activity at its surface for intimate bonding or welding conditions.

While the piston body is being prepared, the preformed steel band is also being prepared. The steel of which the band is made can be of any desired hardness to permit easy machining without loss of adequate reinforcement characteristics. Its preparation involves metallizing its bonding surface with aluminum at a temperature around 900° F. Thereafter, the temperature of the band is brought rapidly to a temperature which activates aluminum to diffuse into the steel to form an interlayer of gradient Fe-Al alloy. At the temperatures noted the two elements are then brought together for fusion of the defined aluminum coating on the steel ring with the molecular coating on the aluminum body. The surface aluminum portions of the two elements being molecularly active as activated by high frequency induction heating, fuse intimately at the surface boundary protected by the oxide preventing coating interlayer. The aluminum welds against the molybdenum coating as it cools under a mechanical pressure created by a shrink fit or by a machine. Thereafter, the integrated piston is handled and machined as a unit.

Thus, one of the objects of the present invention is to provide a rapid and improved method for bonding preformed ferrous metal members to preformed aluminum bodies.

A further object of the invention is to provide a method of integrating ferrous metal and aluminum elements under low cost mass production conditions involving conventional machining tolerances between the elements and including temperature conditions that are easy to attain and are not deleterious to the metals.

A further object of the invention is to convert temperature measurements to time increments under controlled induction frequency conditions to facilitate high speed production of pistons having uniform quality bonds.

These being among the objects of the invention, these and further objects will appear from the drawings, the description relating thereto and the appended claims.

In the drawings:

FIG. 1 shows a rough forging of an aluminum piston blank;

FIG. 2 shows the blank as turned down approximately 1/32" to 1/8" over the piston ring area depending upon piston sizes;

FIG. 3 shows the turned down portion, once it is chemically cleaned being disposed in an atmosphere hood within an induction furnace coil. A chlorine atmosphere is applied and the introduction heater is timed to bring the temperature of the surface metal of the turned down portion to 900° F. for five seconds;

FIG. 4 shows the hood removed and the turned down portion quickly metallized with molybdenum or equivalent metal to provide a mono-molecular layer of the metal thereon for protection against an aluminum oxide film forming thereon subsequently;

FIG. 5 shows the metallizing of a band of #1045 steel internally with pure aluminum to a depth of .001" at a temperature of 800° to 900° F.;

FIG. 6 shows the metallizer removed and the band brought to 1450° for 15 seconds to diffuse the aluminum into a ferrous metal band such as steel;

FIG. 7 shows the band at a temperature between 1000° and 1450° F. slipped into place on the piston while the aluminum body is at a temperature of approximately 900° F.;

FIG. 8 is a side view of the cooled piston body finished to size and with the piston ring grooves therein ready for use;

FIG. 9 is a sectional view taken diametrically through a piston constructed to embody teachings of the invention;

FIG. 10 is a sectional view similar to FIG. 9 showing another embodiment thereof;

FIG. 11 is a sectional view through a brake drum unit and shoe for a motor vehicle embodying teachings of the invention; and

FIG. 12 is a micro-photograph of the novel interface relationship between metals employed to embody teachings of the invention.

Referring now to the drawings in further detail, a preformed piston body or blank **10** made of aluminum by casting or preferably by forging is shown in FIG. 1. The blank has a head **14**, skirt **13** and axially aligned openings **15** to receive a wristpin (not shown). The blank of FIG. 1 is mounted in a machining device according to conventional machine shop practice and preferably a rough cut is taken throughout its length and a further cut approximately 1/32" to 1/8" deep is taken as at **17** in FIG. 2 to provide a predetermined reduced diameter over the ring groove area **12** within inspection tolerances. The depth of the cut **17** can be varied for different sizes of pistons and the different thicknesses of bands that are to be received thereon, but once determined for a particular piston the depth should be just enough to receive a predetermined ferrous metal band thereon allowing for a shrink or pressure fit which when finally machined after installation will have a predetermined thickness within production tolerances that are engineered for the control of weight balance and strength. In this connection, such a band is shown at **36** preformed preferably of ferrous metal from tube stock for uniformity and installed as later described. Both the piston body and band are chemically cleaned before the steps hereinafter described are taken.

The piston blank thus machined is mounted and rotated slowly upon a ceramic turntable **18** which is preferably recessed at **20** to receive the skirt portion **13** therein to a depth at which the reduced portion **17** is exposed above the upper face **24** thereof. An atmosphere hood **26** having an inlet **28**, outlet **30**, and carrying an induction heating coil **32** utilizing high frequency induction is lowered over the reduced portion **17** of the piston and a dilute chlorine gas is circulated through the hood. The exhaust at **30** runs continuously for human safety reasons while the inlet is operative only when the hood is lowered in place. Rotation assures uniform application of the atmosphere over the surface of the reduced portion **17**. The induction coil **32** is energized in timed relation to bring the heat of the piston blank **10** to approximately 900° F. for an average of 5 seconds, depending upon the aluminum body mass, preferably with an induction frequency of 100,000 to 500,000 c.p.s. so as to penetrate beyond the surface metal as little as possible. At this heat and within this time the chlorine gas provided is expected to dissolve and remove the aluminum oxide present on the surface of the reduced portion **17**. It is preferred to determine the chlorine gas dilution empirically for the optimum results described without necessarily increasing the time cycle which incidentally is compatible with the time of preparing the ferrous metal band.

Thereafter, while the reduced portion **17** remains at this temperature the hood **26** and associated reduction coil **32** is removed and a metallizing gun **34** is immediately advanced and moved longitudinally of the piston as indicated in broken lines **37** and the arrow **35** to spray a mono-molecular layer of non-oxidizing metal over the reduced portion **17** to stabilize the surface with a non-oxidizing metal for handling thereafter. This metal can be chosen from a group characterized preferably as being capable in a molten spray condition of boiling or vaporizing the surface aluminum when driven against it. This assures a fuse bond between unoxidized metal surfaces and provides a stable exposed surface which will not oxidize in air, certainly within a short period of time at 900° F. Such metals include molybdenum, tungsten, titanium, cobalt, nickel, columbium, palladium, rhodium an iridium. Of these metals, molybdenum or tungsten is preferred and a spray distance of appreciably less than 3" is desirable, such as 2½". The heat of the molten spray will maintain the surface temperature of the piston and when completed in a matter of seconds the gun **34** is retracted and the piston blank **10** is ready to receive immediately the ferrous metal band whose concurrent preparation will now be described.

In the meantime, the ferrous metal band **36** has been mounted on a ceramic turntable **40** (FIG. 5) for rotation about its axis inside of a non-rotating induction heating coil **42** ready to receive on the inside surface thereof a layer **43** approximately .001" thick of pure aluminum applied by a metallizing gun **44**. The metallizing gun **44** is then advanced and turned on to apply the pure aluminum to the depth desired. Thereafter the gun **44** is retracted (FIG. 6) and the temperature of the band **36** is quickly raised to a temperature of 1450° F. and held there by the coil **42** for approximately **15** seconds to melt the aluminum coating **43**. Whereupon, the coil **42** is raised from the turntable **40** far enough for the ring to be mechanically gripped for removal and placed over the reduced portion **17** of the piston blank **10** to cool and shrink thereon (FIG. 7). Thereafter, the assembled piston body is removed from the turntable **18** and permitted to cool to provide a permanently integrated piston body of fused elements now identified with the numeral **50**. It will be noted that to facilitate removal, the turntable **18** (FIG. 7) has a raisable central portion **21** (FIG. 3) which lifts the piston **50** out of the cavity **20** for ready handling.

The thickness of the spray coat of aluminum **43** and the brief time that the aluminum is molten, i.e. in a "muddy condition," is so determined that the inner portion of the aluminum diffuses into the ferrous metal and alloys therewith to provide an interlayer **45** of gradient Fe-Al alloy (FIG. 12) beween the surface aluminum **43** and the ferrous metal **36** to which it fuses. This interlayer is less than the thickness of the aluminum layer and is preferably by way of example approximately one-half the total thickness of the aluminum in such a relation as .0008" to .0011" Fe-Al alloy layer for .0008" to .0013" aluminum overlay on ferrous metal identified as S.A.E.

1045 steel. Such can be determined visually by a 500X microphotograph of a cross-section given a Nital etch (FIG. 12). Thus, a lustrous aluminum coat is provided which is placed under pressure by the more rapid shrinking of the band **36** against the mono-molecular coating **33** as both cool. A chemical bond at the engaging faces is thereby attained that is unbreakable in use. The presence of a lustrous coat is a visual check during production to assure that no intrusions are present.

After cooling, the integrated piston body **50** is finish machined throughout its length (FIG. 8) to its production tolerances and the ring grooves **52** are cut through the band **36** and into the substrate aluminum ready for final inspection and use. The cutting tools need only be made of high-speed tool steel if desired.

It has been mentioned that the oxidized aluminum surface over the reduced portion **17** need not be removed before metallization with molybdenum. If the step of preliminary removal of oxidized aluminum is omitted, it is desirous to take the piston body as soon after the diameter reducing cut is made. In this instance it can be wire brushed vigorously to surface harden the aluminum and thereafter it is brought up to the temperature noted and metallized. Molten spray molybdenum of course is relied upon to boil away the oxidized aluminum surface to place the molybdenum particles into unoxidized metal-to-metal fused relationship therewith, preparatory to receiving the aluminum coated band thereon as already described.

It is possible that the molybdenum coat may be minimized if the piston receives on the stripped area **17** the ring **36** before the area becomes again oxidized in any way. It is preferred to employ the molybdenum for assured production uniformity, particularly if the piston is permitted to cool and is reheated to receive the band.

It will be noted that the temperatures given also provide a very desirable temperature relationship with respect to the compression exerted upon the aluminum **43** trapped within the ferrous metal band **36**. The piston blank temperature can be as high as 900° F. and the band temperature as low as 1000° F. when brought together. The aluminum interfaces diffuse together through the molybdenum and bond or weld permanently under the pressure exerted by the band without imposing upon the band an unfavorable tension.

Moreover, a thinness of a preformed band is possible that permits it to "breathe" without undue stress with any warm-up or cooling-off of the product which occurs in use while performing work expected of it whether it works under tension or compression. Moreover, it has been found that under such work cycles the aluminum tends to diffuse deeper and deeper in the ferrous metal to provide a deepening alloy bond.

Referring now to FIG. 9, the piston is further treated on the head area **14** if desired, preferably by a spray coating as described in said Patent No. 2,833,264, or a thin walled cup or sheet of ferrous metal **60** can be applied under heat and pressure in accordance with the teachings herein set forth. In either event, a flash coating of copper **62** (FIG. 9) is applied to the surface by spray or electrolysis and it has been found that with the heat of engine combustion accumulated in the copper and ferrous metal, the copper oxide which forms on the surface under combustion conditions serves as a catalyst which not only assures complete combustion of the gasoline fuel utilized by an internal combustion engine while work is being done but prevents the formation of benzipyoidine and other unhealthy substances deleterious to human life in the exhaust gases which occurs with an over-rich fuel supply to the engine, particularly during idling.

In FIG. 10, the band **36***a* is narrower and leaves a space above it to receive the edge **72** of a copper cup **70** thereagainst. In this instance the crown **74** of the piston is also stripped and sprayed with a layer of molybdenum

and the inside of the cup is sprayed with aluminum and brought to a melting temperature to diffuse into the copper whereupon the copper cup is disposed in place under pressure from a mechanical press (not shown) until cool and the aluminum layers fuse. Whether the molybdenum layer will be thick or thin depends upon the same considerations of FIG. 9 regarding whether it should serve as a heat rejection weir and to what degree. Moreover, the CuO catalyst may be formed by flame spraying, deposition or sintered powder metallurgy. If carriers are desired Al_2O_3 or SiO_2 can be used by deposition upon small pellets thereof and then sintering.

In fact, in connection with the composition of the catalysts **62** and **70** shown in connection with FIGS. 9 and 10, and the thickness of the molybdenum coating serving as a weir, it is appreciated that the working temperatures of a combustion envelope varies widely in an internal combustion engine whether it is air cooled or watercooled and also the air fuel ratio varies. Therefore, the resulting constituents of the exhaust gases varies also. Of these constituents which may be exhausted two gases, NO and CO, are the two most likely to create problems from a health and smog viewpoint. Separately they are dangerous and when together in the atmosphere in sunlight, they are converted to produce smog having by-products also dangerous to health, comfort, etc.

It has been found that the catalysts **62** and **70** on the wall of the combustion envelope comprising preferably CuO kept at a surface temperature above 300° C., minimizes the production of NO and CO whenever either one or both are likely to appear. As noted herein the thickness of the molybdenum or a ferrous layer **60** between the catalyst **62** and the aluminum substrate metal at **14** is so determined as to retard rejection of combustion heat to the aluminum body enough to assure maintenance of 200° C. during engine no load idling conditions.

The presence of just the hot wall greatly reduces the problem since it assists full vaporization of wet fuel entering the combustion envelope and thereby enables a fuel enonomy correction that reduces CO. It however does not control the fuel air proportion delivered by commercial carburetors or fuel injectors and such proportions with a given carburetor vary widely due to many factors including use at changing elevations, fuel ratings, etc., generally encountered with general vehicle operations.

With this advance toward a complete combustion of a perfect mixture, the problem is lessened to cope only with minor variations in the fuel-air mixture which cannot be helped. Therefore, the combustion heated catalyst provided by the present invention as a catalyst can handle the minor variations and virtually eliminates the exhaust gas dangers accompanying the variations tolerated in commercial vehicles.

When NO is likely to occur there will also be some oxygen present and insofar as I can ascertain, the formation of NO is inhibited, or if formed, is immediately decomposed as an exothermic reaction in which 2NO $N_2 + O_2$ at catalyst temperatures above 300° C. with a CuO catalyst. This will accomplish almost complete elimination of nitric oxide, the prevalent oxide of nitrogen which is the hardest to handle.

On the other hand, if an unvaporized or hydrocarbon fuel is unburned and CO is formed, oxygen will also be present and CO present is consumed by oxidization accelerated by the CuO catalyst at temperatures above 220° C.

Above 225° C. concentrations as high as 7% CO content were handled with satisfactory results regardless of water vapor content and hydrocarbon (oil vapor) present in low concentrations were also consumed to provide work energy. The usual turbulence developed by the compression stroke is a help and the location of the catalyst on the piston head is particularly effective.

Referring now to FIG. 11, an aluminum brake drum

80 for an aluminum motor vehicle road wheel is illustrated sectionally where the braking surface 82 on a preformed internal band of ferrous metal 84 is externally welded to the aluminum body 78 in a drum cavity 86 which is preferably formed by a forging process and machined to concentricity. The brake shoe is illustrated at 85. The method of making the bond or weld is similar to that already described in connection with the piston 50. The brake drum cavity 86 is stripped of aluminum oxide and metallized with a bonding metal, at the devated temperature noted. The outside surface of the ferrous metal band is metallized with aluminum and heated to a high temperature rendering the aluminum molten to diffuse into the ferrous metal surface and provide a Fe-Al alloy interlayer as already described. Thereafter, the band is allowed to cool to approximately 1000° F. and with the aluminum drum at a temperature of 900° F. the two parts are pressed together with a compressive pressure fit. Preferably thereafter the ferrous metal is again raised momentarily to approximately 1500° F. to expand it and assure weld temperature and pressure at the interface while the aluminum is being cooled rapidly to contract it and place the welding surfaces under pressure.

Reference is made to FIG. 12 where a depiction of a microphotograph of the prepared bond is shown with the mono-molecular layer 33 of the bonding metal between two layers of aluminum 12 and 43 and a diffusion layer of Fe-Al alloy is disposed between the outermost layer of aluminum 43 and the ferrous metal 36.

Although the invention can be used with cast as well as forged aluminum bodies, it is primarily of interest with respect to forged bodies because the porosity of castings and the trouble and expense of casting molten aluminum against a reinforcing body with doubtful results is eliminated.

Moreover, dangers of flaking, plastic deformation, blistering and distortion that can occur with aluminum bodies subjected throughout to high temperatures for long periods of time are eliminated with the present invention because of the rapidity, short use and limited penetration of the heats employed. A temperature below, but close to the temperature of incipient fusion or eutectic melting of aluminum can be used quite safely. Even if all of the oxidized aluminum is not stripped by the chlorine gas, the mono-molecular molybdenum layer assures an unoxidized bonding surface which permits the brevity of high heat application found to be desirable for ultimate welding.

Having thus described the invention and several embodiments thereof, it will be appreciated by those skilled in the art how the objects of the invention are accomplished and how various and further modifications can be made including reinforced aluminum bearings without departing from the spirit of the invention, the scope of which is commensurate with the appended claims.

What is claimed is:

1. A preformed body having a defined face of high heat conductive metal, a mono-molecular layer of particles of molybdenum on said face whose innermost particles are molecularly mixed with unoxidized metal of said high heat conductive metal, a preformed element of ferrous metal on said layer, means for bonding said layer to said ferrous metal including interfused layers of Fe-Al alloy and aluminum, and recess means on said body through said layer and preformed element exposing the metal of said body for heat rejection through said recess means.

2. A piston comprising a preformed body of high heat conductive metal having spaced wall portions of unoxidized metal circumferentially around it defining a rounded contour, a cylindrical body of preformed ferrous metal for each wall portion, means for welding said cylindrical bodies to each unoxidized metal wall portion including fused layers of ferrous aluminate and aluminum, said cylindrical bodies defining a circumferential groove therebetween extending through to said high heat conductive metal for receiving a piston ring therein in direct heat exchange contact with said high heat conductive metal at the inner portion of the groove.

3. A piston for an internal combustion engine comprising a preformed body of high heat conductive metal having spaced wall portions circumferentially around it defining a rounded contour, a layer of particles of molybdenum on each wall portion whose innermost particles are molecularly alloyed with unoxidized metal of said wall portions, a cylindrical body of preformed ferrous metal, means for bonding said cylindrical body to a respective layer of particles upon each wall portion including fused layers of Fe-Al alloy and aluminum, said cylindrical bodies defining a circumferential groove therebetween extending through to said high heat conductive metal for receiving a piston ring therein in direct heat exchange contact with said high heat conductive metal at the inner portion of the groove.

4. A piston comprising a piston body of high heat conductive metal having spaced wall portions circumferentially around it defining a rounded contour, a layer of particles on each wall portion of a metal taken from a group consisting of molybdenum, titanium, colbalt, nickel, columbium, palladium, rhodium, tungsten and iridium whose innermost particles are molecularly mixed with unoxidized metal of said wall portions, a preformed cylindrical body of ferrous metal bonded to each layer upon each wall portion by interfused layers of Fe-Al alloy and aluminum under pressure between said bodies, said cylindrical bodies defining a circumferential groove therebetween extending through to said high heat conductive metal for receiving a piston ring therein in direct heat exchange contact with said high heat conductive metal at the inner portion of the groove.

5. The combination called for in claim 1 in which the preformed element includes in part an area spaced from said recess means and including thereon an exposed layer of catalytic copper oxide bonding to said layer of ferrous metal in heat exchange relationship therewith.

6. A piston for an internal combustion engine comprising a body of high heat conductive metal having a head portion, a preformed cover element of ferrous metal bonded to said head portion in high heat conductive relationship, and an exposed layer of catalytic copper oxide bonded to said cover element in heat exchange relationship therewith.

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KARL J. ALBRECHT, *Primary Examiner.*