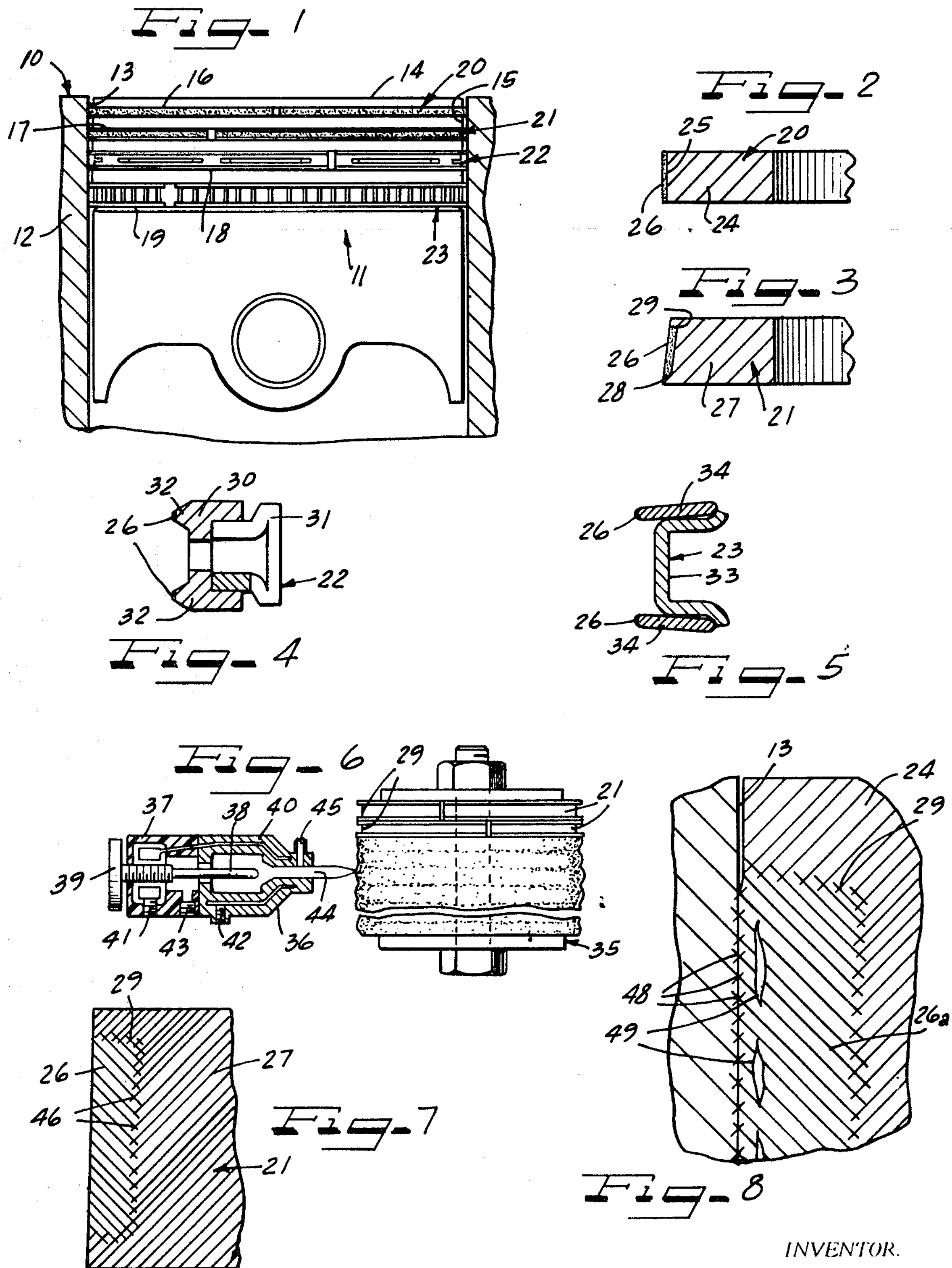
Sept. 20, 1971 H. E. McCORMICK 3,606,359

TUNGSTEN CARBIDE COATED PISTON RINGS

Filed Aug. 8, 1969



INVENTOR.
HAROLD E. McCORMICK

BY Hill, Sherman, Meroni, Gross & Simpson ATTORNEYS

United States Patent Office 3,606,359
Patented Sept. 20, 1971

1

3,606,359

TUNGSTEN CARBIDE COATED PISTON RINGS

Harold E. McCormick, Ballwin, Mo., assignor to Ramsey Corporation, St. Louis, Mo.

Filed Aug. 8, 1969, Ser. No. 848,623
Int. Cl. F16j 9/00
U.S. Cl. 277—224 10 Claims

ABSTRACT OF THE DISCLOSURE

Piston rings, including compression and oil control rings, for internal combustion engine pistons, having a bearing face of an alloy formed in situ on the ring from a plasma jet stream. The alloy is composed of refractory metal carbides such as tungsten carbide in solid solution with another metal, such as cobalt, to provide a hard wear phase with the carbide particles relatively free from sharp edges and corners and a somewhat softer matrix phase composed of metals such as nickel, chromium, boron, and aluminum. The aluminum should be present in a minor amount such that even minor scuffing of engine cylinders is avoided. The coating is very hard and refractory, possesses a higher tensile strength than heretofore used piston ring facings, does not scuff, has improved abrasive wear resistance, and operates compatibly with the engine cylinders. The carbides in the coating will not pull out in operation of the ring because they are in solid solution and do not have a sharp particulate form. The nickel, chromium and boron in the alloy provide binders improving the mechanical strength of the coating and the hardness of the matrix.

BACKGROUND OF THE INVENTION

Field of the invention

This invention pertains to the packing ring or piston ring art and to the provision of bearing faces on piston rings which will resist adhesive wear, abrasive wear, and corrosive wear encountered in high compression-high speed, and high temperature operating internal combustion engines without unduly wearing the engine cylinder.

Description of the prior art

Piston rings, including compression rings and oil control rings, coated with hard facing metal with good scuff resisting properties are disclosed in the following United States Letters Patents:

Roy D. Anderson, 2,905,512, issued Sept. 22, 1959
Melvin W. Marien, 3,133,739, issued May 19, 1964
Melvin W. Marien, 3,133,341, issued May 19, 1964
Donald J Mayhew, et al., 3,281,156, issued Oct. 25, 1966

While the flame spray applied molybdenum hard facing material disclosed in these patents afforded the heretofore best known performances for piston rings in high-compression, high-temperature operating internal combustion engines, engine builders continue to increase compression ratios, operating temperature ranges, and speed requirements and continue to demand even greater perfection in piston ring performance. While it was known that increasing the hardness of the facing metal on the piston rings would enhance the wear resistance of the ring, metals or alloys more refractory than molybdenum were found to induce engine cylinder wear and to have insufficient mechanical strength to withstand high speed-high compression operation. Best heretofore known thermally applied molybdenum piston ring facings have a tensile strength of approximately 9000 p.s.i. or less.

Attempts to provide piston rings with refractory facings composed of refractory metal carbides such as chromium carbides, tungsten carbides, and silicon carbides have heretofore been unsuccessful because the carbides appear as sharp edged or globular particles which pull out of the coating in operation in the engine causing high piston ring and cylinder wear.

2

The just-discussed problem of carbide pull-out has now been overcome as outlined in co-pending, commonly assigned application Ser. No. 696,645, filed Jan. 9, 1968, now U.S. Pat. 3,539,192, granted Nov. 10, 1970. However, it has been subsequently discovered that in some few occasions scuff resistance of the coating has been somewhat marginal. That is, some scoring and scraping of the relatively soft wear surfaces of the cast iron cylinder or cylinder lining has been noted upon occasion. After extensive investigation it has been discovered that the problem of scoring and scraping is due in most part to presence of excessive amounts of aluminum in the alloy.

It would therefore be a substantial advance in the art if the plasma jet flame applied refractory metal carbide alloy described in the above application could be somehow improved whereby scuffing is substantially eliminated even under the most severe conditions.

SUMMARY OF THE INVENTION

The present invention now provides hard-faced piston rings, giving greater performance in high-speed, high-compression, high temperature operating engines than heretofore known piston rings. The rings of this invention are coated with a plasma jet applied refractory metal carbide alloy formed in situ on the ring. Suitable refractory metal carbides include the carbides of tungsten, titanium, tantalum, columbium, moybdenum, vanadium, chromium, zirconium, hafnium, silicon, and boron.

The just-discussed refractory metal carbide is utilized as an alloy with additional materials, one of which is aluminum which is present in a minor amount such that scuffing of engine cylinders via contact with said piston ring bearing face is avoided. Additional alloy ingredients other than aluminum which may be present in substantial amounts include one or more of cobalt, nickel, boron and/or chromium.

In general the term "refractory metal carbide" as used herein means a carbide of a metal or metalloid having a melting point above about 3000° F. and a hardness above about 1500 Vickers DPN (diamond penetration number) with a 40 gram load, referred to as "40 DPN." These carbides have very low solubility in cobalt which is used in the production of sintered carbides for forming bodies of high hardness and compressive strength. According to this invention, however, the carbides are placed in solution with cobalt by virtue of the very high temperatures obtainable in the plasma jet stream. The carbide facing material of this invention, contrary to previously tested carbide facing materials for piston rings, has surprisingly eliminated heretofore encountered scuffing and does not appreciably wear the cylinder liner even when operated under conditions which cause heretofore known carbide faced piston rings to scuff, adversely wear the cylinder liner, and disintegrate. The plasma jet applied carbide coatings of this invention, by having the carbides in solution in the alloy, eliminate the heretofore encountered pull-out problem causing the scuffing and wear.

The carbide content of the alloy should also be controlled to insure retention of the refractory metal carbide in solution with the cobalt and to provide an alloy of sufficient strength to withstand the thermal bi-metal expansion forces combined with the mechanical stresses encountered in the engine. Further, it is highly desirable to provide a facing material which can be finished by grinding on conventional silicon carbide and aluminum oxide grinding wheels and excessive amounts of the refractory metal carbide in the alloy will provide a facing material which is too hard to finish by conventional grinding methods. Therefore, in general, the refractory metal carbide content of the powder mixture fed to the plasma jet stream to produce the in situ formed hard facing material on the piston ring should be between about 25 to 55 percent by weight of the powder.

In accordance with the preferred embodiment of this invention, ferrous metal compression rings composed of conventionally cast nodular iron of about 3½ percent carbon content by weight, thin rail rings from oil control assemblies composed of carbon steel such as S.A.E. 1070 and the like base metal rings, are coated from a plasma jet stream, receiving a powder of the following composition:

25 to 55 percent by weight tungsten carbide
4 to 8 percent by weight cobalt
25 to 45 percent by weight nickel
3 to 7 percent by weight chromium
Less than 1 percent by weight aluminum
0 to 3 percent by weight boron
Balance substantially iron

The aluminum content of the above powder composition is particularly critcal if one is to realize excellent scuff resistance of the coating. As noted above, the aluminum content should be less than 1%, and more preferably falls between about 0.5 to about 0.9%. A greatly preferred powder composition comprises 0.56–0.88% by weight of aluminum.

The tungsten carbide content of the powder may be admixed with or replaced by other carbides such as the carbides of metals and metalloids from the group including titanium, tantalum, columbium, molybdenum, vanadium, chromium, zirconium, hafnium, silicon, and boron.

The plasma jet has a fuel gas preferably composed of a mixture of nitrogen and hydrogen and an inert carrier gas, preferably nitrogen, argon, or helium, which will prevent oxidation of the ingredients of the powder, even at the extremely high temperatures (up to 30,000° F.) that might be developed in the jet stream. The compression rings are preferably peripherally grooved, and the groove is filled with an alloy resulting from the plasma jet application of the powder, which alloy has the refractory metal carbide in solid solution with coablt in a matrix of nickel, chromium, and aluminum. The matrix is composed principally of nickel and chromium and the aluminum is in the form of metallic aluminum or aluminum oxide. This alloy has a melting point of approximately 5,000° F., has about five times the wear resistance of the heretofore used molybdenum or chromium hard facing metals and reduces bore wear and scuffing far beyond the best results obtained with previously tested hard carbide faced piston rings. The alloy has excellent mechanical strength and shock resistance under a wide range of severe temperature conditions. Tensile strengths in excess of 15,000 p.s.i. have been obtained.

It is then an object of this invention to provide improved piston rings with hard-faced bearing surfaces composed of a plasma jet applied refractory metal carbide alloy.

It is also an object of this invention to provide a piston ring coating containing refractory metal carbides in solution in the facing alloy, reducing or eliminating the possibility of carbide pullout during engine operation.

A further object of this invention is to provide rings with a temperature and wear-resisting hard-facing refractory metal carbide alloys which will not unduly wear an engine cylinder and which have a greater strength under wide temperature ranges than heretofore known hard facings on piston rings.

Another object of this invention is to increase the operating parameters of piston rings by providing plasma jet coatings of refractory metal carbides thereon.

Another object of this invention is to provide piston rings with hard-facing alloys which are formed in situ on the ring by a plasma jet from a powder containing up to 55 percent by weight of a refractory metal carbide.

Still another object is to provide a high strength hard, wear resistant piston ring refractory metal carbide facing which may be processed using conventional silicon carbide or aluminum oxide grinding wheels as opposed to the more expensive diamond wheel grinding processes.

A special object of the invention is to provide improved piston rings with hard-face bearing surfaces composed of a plasma jet applied refractory metal carbide alloy in combination with other alloy ingredients, to provide piston ring coatings of exceptional scuff resistance.

Other and further objects of this invention will be apparent to those skilled in this art from the following detailed description of the annexed sheet of drawings which by way of preferred examples illustrates several embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view, with parts in cross section, of an engine piston and cylinder assembly, wherein the piston has ring grooves equipped with compression and oil control rings each having a bearing face engaging the cylinder which is composed of in situ formed plasma jet applied carbide alloys, according to this invention.

FIG. 2 is an enlarged fragmentary cross-sectional view of the top compression ring in the piston of FIG. 1.

FIG. 3 is a view similar to FIG. 2, but illustrating the second compression ring in the piston of FIG. 1.

FIG. 4 is a view similar to FIG. 2, but illustrating the oil control ring in the third ring groove of the piston of FIG. 1.

FIG. 5 is a view similar to FIG. 2, but illustrating the oil control ring in the fourth ring groove of the piston of FIG. 1.

FIG. 6 is an elevational view of an arbor of piston rings being plasma jet coated in accordance with this invention.

FIG. 7 is a greatly enlarged fragmentary cross-sectional view of a compression piston ring having a bearing face band of carbide alloy, bonded in a peripheral groove of the ring in accordance with this invention.

FIG. 8 is a greatly enlarged somewhat diagrammatic view illustrating the manner in which a piston ring coated with prior used hard facing metal will scuff under severe operating conditions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The piston and cylinder assembly **10** of FIG. 1 illustrates generally a conventional 4-ring groove internal combustion engine piston, operating in an engine cylinder. The assembly **10** includes a piston **11** and an engine cylinder **12** with a bore **13**, receiving the piston **11**. The piston **11** has a head **14** with a ring band **15** having four peripheral ring grooves **16, 17, 18** and **19** thereabound. The top ring groove **16** has a split solid cast iron compression or fire piston ring **20** therein. The second ring groove **17** has a split solid second compression ring **21** somewhat wider than the ring **20**. The third ring groove **18** carries a two-piece oil control ring assembly **22**. The fourth or bottom ring groove **19** carries a three-piece oil control ring assembly **23**.

As shown in FIG. 2, the top compression or fire ring **20** has a main body **24** composed of cast iron, preferably nodular gray iron, with a carbon content of about 3½ percent by weight. The outer periphery **25** of this ring is covered with a plasma jet applied carbide alloy coating **26**.

As shown in FIG. 3, the second compression ring **21** has a main body **27** composed of the same type of cast iron as the body **24** of the ring **20**. The outer periphery **28** of the body **27** is inclined upwardly and inwardly from the bottom edge of the ring and a peripheral groove **29** is formed around this inclined periphery. The groove **29** is filled with the carbide alloy **26**.

As shown in FIG. 4, the oil control ring assembly **22** in the third ring groove **18** is composed of a one-piece flexible channel ring **30** and a sheet-metal expander ring **31**, having legs extending into the channel for expanding the ring **30**. The ring **30** and the expander are more fully described in the aforesaid Mayhew et al. Pat. 3,281,-156.

The one-piece oil control ring **30** has a pair of axially spaced, radially projecting beads **32**. The peripheries of these beads **32** are coated with the coating **26**.

In FIG. 5, the oil control ring assembly **23** includes a resilient spacer-expander ring **33** supporting and expanding split thin rail ring **34**. The assembly **33** is of the type disclosed in the aforesaid Marien patents. The outer peripheries of the rail rings **34** are coated with the coating **26**, according to this invention.

From the above description, it will be understood that the bearing faces of each of the compression and oil control rings **20**, **21**, **22**, and **23** are coated with the carbide refractory alloy according to this invention. These bearing faces **26** ride on and sealingly engage the bore **13** of the engine cylinder **12**, and the rings are compressed in the bore **13**, so as to expand tightly against the bore wall, and maintain a good sealing sliding engagement therewith.

As shown in FIG. 6, the coatings **26** are applied on the rings as for example on the grooved rings **21** by stacking a plurality of the rings on an arbor **35**, with the rings compressed so that their split ends will be in abutment. The arbor clamping the stack of rings in their closed, contracted position, may be mounted in a lathe and the peripheries of the rings machined to form the grooves **29** therearound. The outer peripheries of the rings **21** on the arbor are then coated with the coatings **26** from a plasma jet spray gun **36**. The gun **36** includes an insulated casing such as nylon 37, from which projects a rear electrode **38**, the projection of which is adjustably controlled by a screw knob **39**. The front face of the casing receives a front electrode **40**. The casing **37** and electrode **40** are hollow and water-jacketed so that coolant may circulate therethrough from an inlet **41** to an outlet **42**. Plasma jet gas is fed through an inlet **43** into the chamber provided by the casing **37** and the electrode **40** to flow around the electrode **38**.

The front end of the electrode **40** provides a nozzle outlet **44** for the plasma flame and the ingredients to form the alloy of the coating **26** are fed to this nozzle through a powder inlet **45**, just an advance of the discharge outlet of the nozzle.

A plasma composed of ionized gas is produced by passing the plasma gas from the inlet **42** through an electric arc established between the electrodes **38** and **40**. This plasma gas is non-oxidizing and may be composed of nitrogen and hydrogen with argon or helium as a carrier. The plasma flame exuding from the nozzle **44** draws the alloy-forming powder therewith by aspiration and subjects the powder ingredients to such high temperatures as to cause them to alloy. The jet stream carries the alloy into the bottom of the groove **29** of each piston ring and fills the groove.

The preferred powder fed to the powder inlet **44** of the gun **36** is composed of tungsten carbide, cobalt, nickel, chromium, boron and aluminum, in the proportions indicated herein above, with a preferred powder mixture of the following composition:

40 percent by weight tungsten carbide
6 percent by weight cobalt
38.8 percent by weight nickel
6 percent by weight chromium
1 percent by weight boron
0.7 percent by weight aluminum
Balance substantially iron, with minor amounts of silicon and carbon.

The preferred deposited coating **26** is a tungsten carbide alloy wherein the tungsten carbide ingredients is bound in a fused and alloyed matrix of the nickel, chromium, aluminum and boron. The alloy **26** as illustrated in FIG. 7 is actually formed in situ in the groove **29**, and is bonded to the base body **24** of the ring along a diffused interface or welded zone **46**. This interface, or zone **46**, is composed of the materials of the alloy **26** and the material of the ring body **24**.

The alloy **26** has a hexagonal close pack crystalline structure in a matrix composed principally of nickel and chromium. This alloy has three principal phases, the hardest phase being composed of tungsten carbide in solution with the cobalt and having a Vickers hardness of 2900 to 4000 DPN (diamond penetration number) with a 40 gram load (40 DPN). In this phase the carbides are well in solution and are not sharp. The second phase is also composed of tungsten carbide and cobalt with the carbides in solution but has a particle hardness in the range of 2100 to 3200 Vickers, 40 DPN. The third phase is a matrix phase with a Vickers particle hardness in the range of 900 to 1200, 40 DPN. This phase is composed principally of nickel and chromium with boron, if present, uniformly distributed in the matrix. A fourth phase comprising only about 4 percent by volume of the final coating consists principally of aluminum and has a hardness of approximately 500 Vickers 40 DPN.

The tungsten carbides in the preferred alloy consist principally of W_2C and $(WCo)_2C$ and may be considered to have the following formula:

$$W_2C(WCo)_2C$$

During the jet spray application, it is desired to maintain a temperature in the groove **29** such that will prevent excessive melting and burning away of the body metal **24**. For this end result, the arbor of rings is preferably cooled with an external blast of inert gas impinging on both sides of the jet flame. It is desired to keep temperatures of the rings **21** in the arbor around 400 dergees F. or less. It is not necessary to provide any subsequent heat treatment for the plasma jet coated rings other than allowing the rings to air cool.

The powder fed to the inlet **45** is metered preferably with the aid of an aspiring gas, vibration, mechanical gearing, etc. All of the powder is completely melted and penetrates into the center cone of the plasma jet flame.

To get the carbides in the solution with the cobalt it is not only important to use the very high temperatures available in the plasma jet stream but the so-called spray parameters of the powder fed to the stream are important since if the tungsten carbide content of the powder is appreciably over 55 percent by weight it is very difficult to retain the carbides in solution and if the carbide content is appreciably below 25 percent by weight, wear and scuffing of the cylinder occurs. Thus an alloy having a tungsten carbide content of 66 percent, a nickel-chromium-boron binder content of 18 percent, and a nickel aluminide content of 7 percent was found to cause excessive cylinder wear and quickly scuffed. The material was quite brittle and flaked during tests. An alloy with a tungsten carbide content of 88 percent could not be finished on a conventional grinding wheel. An alloy with a tungsten carbide content of 22 percent was found to quickly scuff and to increase the bore wear beyond the amounts encountered with the alloys of this invention.

The scuffing action is illustrated in FIG. 8, wherein the coating **26A** filling the groove **29** in the piston ring **24** is illustrated as having an adhesive affinity for the wall of the engine bore **13** along the area **48** of sealing engagement with the bore wall. This adhesion and the brittleness of the coating **26A** causes the metal in the groove **29** to break away along lines of fracture indicated at **49**. This produces the scuffing effect on the bearing face and destroys not only the sealing efficiency of the bearing face but also causes abrasion of the cylinder bore **13**.

The coatings **26** of this invention are less porous than the heretofore known flame sprayed molybdenum coatings. For example where such flame sprayed molybdenum coatings have a porosity in the range of 15 to 30 percent, the coatings **26** only have a porosity around 7 percent. This provides much greater corrosion resistance in the bearing face.

Since the softening points of the in situ formed alloy coatings **26** of this invention are over 1900 degrees F., the bearing face can of course withstand much higher temperatures than the prior known piston ring coating materials.

The alloys of the coatings **26** also have about 5 times the wear resistance of the heretofore used molybdenum and chromium hard-facing material, and therefore much thinner coatings can be used. It has been found that coating thicknesses of .002 inch in oil control ring assemblies and from .002 to .004 inch in compression rings are quite satisfactory. This of course reduces the expense of producing the rings.

The rings of this invention have been severely tested both in actual high performance diesel engine operation and have also been subjected to thermal stress and oxidation resistance tests. The tungsten carbide alloy coatings of this invention withstood thermal stress tests which consisted of heating the piston rings with the coating in the stressed condition to 1800 degrees Fahrenheit for 100 hours. Post test photomicrographic examination showed this coating to withstand this test, whereas previously used molybdenum coating will not withstand this test at 750 degrees F.

The alloys of the coatings **26** can be ground with standard dressing wheels even though they have a superficial hardness far in excess of the heretofore known hard facing materials for piston rings. Thus, the alloys of the coatings **26** were found to have a hardness of more than 1,500 kilograms per square millimeter on the Vickers scale, whereas the best heretofore known hard-facing materials for piston rings had a Vickers hardness around 1,000 kg./sq. mm.

The provision of the alloy coatings **26** in a groove to form a band around the periphery of the piston ring **21**, for example, utilizes the body metal of the ring as a land alongside of the groove to form an initial quick break-in surface for the ring, as described in the aforesaid Marien Pat. 3,133,739. The inclined periphery of the ring **21** may be formed by grinding or by torsional twisting of the ring in use in the ring groove, as described in the Marien patent.

As noted above, the aluminum content is quite critical if one desires to achieve good scuff resistance. This was borne out in a series of comparative tests as follows:

In the first test a high (190 p.s.i.+) B.M.E.P. (Brake Mean Effective Pressure) cylinder was operated in conjunction with piston rings having a bearing face deposited tungsten carbide alloy coating of the following composition:

40% by weight tungsten carbide
6% by weight cobalt
36.5% by weight nickel
6% by weight chromium
1% by weight boron
3% by weight aluminum
Balance substantially iron, with minor amounts of silicon and carbon.

In less than 30 hours of operation some bore distress was noted.

In a second trial the exact same powder composition was used as a bearing ring facing with the exception that the aluminum content was lowered to 0.7% by weight aluminum. The aluminum content was compensated by raising the nickel content to 38.8% by weight. Under the same exact test conditions the high B.M.E.P. (190 p.s.i.+) cylinder was operated for 1000 hours with substantially no bore distress whatsoever being noted after this period of time.

An added advantage was noted when the aluminum content of alloys of the invention was maintained in the minor amounts set out above. Particularly it was noted that the reduced aluminum content reduced the total enthalpy of the exothermic reaction and permitted a decrease in the plasma gun-to-work distance without a resultant loss in bond strength. A change in plasma gun-to-work distance of from 6 inches down to 4 inches increased the deposit efficiency of the spray operation by 20–30% with a resultant savings in material cost.

It will be understood that, while tungsten carbide is the preferred refractory metal carbide, it may be replaced in whole or in part with any one or more of the hereinabove mentioned refractory metal carbides. The refractory metal carbide content may vary considerably as long as the carbides are in solution in the alloy and are relatively free from sharp edges and corners which induce pull-out during operation. For practical purposes the refractory metal carbide content will be between 25 to 55 percent by weight of the powder fed to the plasma jet stream since these parameters insure the scuff-resistance, mechanical strength, and finishing ability of the alloy. The starting powder preferably has the carbides present as individual grains sintered with the cobalt so that in the preferred embodiment the starting powder would have sintered grains containing 40 percent by weight of tungsten carbide and 6 percent by weight of cobalt.

From the above descriptions, it will therefore be understood that this invention now provides piston rings coated with hard facing metals which will give better performance in engine operation than heretofore known, and particularly exhibit surprisingly good scuff resistance. In addition, the coatings while of sufficient hardness nevertheless may be finished by grinding on conventional silicon carbide and aluminum oxide grinding wheels.

I claim as my invention:

1. A piston ring having a bearing face coating composed of at least one carbide of a substance from the group consisting of refractory metals and metalloids in solution with cobalt and alloyed in a matrix containing principally nickel and iron, said carbide being free from sharp edges and corners, said alloy containing not more than about one percent by weight aluminum to reduce scuffing of engine cylinders engaged by the coating, and said alloy being bonded to the body of the piston ring along a diffused interface zone composed of materials of the alloy and the body of the piston ring.

2. The piston ring of claim **1** wherein the aluminum is present in an amount less than 1% by weight.

3. The piston ring of claim **2** wherein the aluminum is present in an amount ranging from about 0.5% to about 0.9% by weight.

4. The piston ring of claim **3** wherein the aluminum present is in an amount ranging from about 0.56% to about 0.88% by weight.

5. The piston ring of claim **4** wherein the aluminum is present in an amount of about 0.7% by weight.

6. A piston ring having a bearing face coated with a plasma jet flame applied refractory metal carbide alloy formed from a mixture of a refractory metal carbide having a melting point above 3000° F., and a hardness above 1500 Vickers 40 DPN, and the following ingredients having the following percentages by weight:

4 to 8% cobalt
25 to 45% nickel
3 to 7% chromium
less than 1% aluminum
0 to 3% boron
Balance substantially iron.

7. The piston ring of claim **6** wherein said piston ring has a ferrous metal ring body and said alloy is bonded to said body along a diffused interface zone composed of materials of said alloy and said body.

8. The piston ring of claim **6** wherein the ingredients forming the alloy has the following percentages by weight:

25 to 55% tungsten carbide
4 to 8% cobalt
25 to 45% nickel
3 to 7% chromium
less than 1% aluminum
0 to 3% boron
Balance substantially iron.

9. The piston ring of claim **6** wherein said aluminum is present in an amount ranging from about 0.5 to about 0.9%.

10. The piston ring of claim **6** wherein the ingredients forming the alloy have the following percentages by weight:

40% tungsten carbide
6% cobalt
38.8% nickel
6% chromium
1% boron
0.7% aluminum
Balance.—Iron with small amounts of silicon and carbon.

References Cited

UNITED STATES PATENTS

3,183,337	5/1965	Winzeler et al.	117—93.1(PFS)
3,326,714	6/1967	Rath	117—93.1(PFS)
3,419,415	12/1968	Dittrich	117—93.1(PFS)

ROBERT I. SMITH, Primary Examiner