FIG. 1

LOAD

14

13

15

11

12   17

16

10

FIG. 2

62   61   63

65

67

66   64

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ABSTRACT OF THE DISCLOSURE

One can avoid the necessity of adding lubricants to a
variety of fluid process assemblies involving relatively
movable opposing surfaces by selecting the composition
of the opposing surfaces. Specifically, the lubricant can
be formed in situ from the fluid used where one surface
is of a mixture of an alloy containing at least 6 atom per-
cent of an element selected from the group consisting of
molybdenum and tungsten, at least 10 percent by volume
of the alloy being an intermetallic compound of molyb-
denum or tungsten having a Vickers Hardness number
of 550–1800, and a softer material that is strong enough
to support the alloy particles in the shape required for
use; the mating surface is either of an alloy containing
at least 50 atom percent iron, at least 1 atom percent
carbon, at least one-half the weight of the remainder of
the alloy being composed of at least one of the following
elements: chromium, manganese, molybdenum and tung-
sten, said element(s) being present as carbide(s) or in a
fully hardened solid solution, and having a Vickers Hard-
ness number of at least 400 or a similar alloy containing
at least 80 atom percent iron and having a Vickers Hard-
ness number of at least 200 or an alloy of 11–15 atom
percent carbon, 1.5–3 atom percent silicon, the balance
being iron, having a Vickers Hardness number of at
least 150; and the fluid is an organic compound capable
of polymerizing to form a lubricant, e.g., petroleum hy-
drocarbons, aliphatic alcohols, and aliphatic aldehydes
having at least 4 carbon atoms. Although one can obtain a
useful lubricating system using the alloy of molybdenum
or tungsten as the first surface and one of the alloys of
iron as the second surface, a substantial improvement
is obtained by using the mixtures set forth herein as
the first surface.

Cross references to related applications

This application is related to the copending application,
Ser. No. 780,879, entitled "Lubricant Producing System"
which was filed on the same date as the present applica-
tion.

Background of the invention

This invention is in the field of functional systems
producing lubrication.

Ideally, a lubricant for the interface of relatively mov-
able (sliding, rubbing, rolling, etc.) opposing surfaces
should serve to completely separate those surfaces. This
condition is known as full-film or hydrodynamic lubrica-
tion. Full-film lubrication physically separates the two
sliding surfaces by a relatively thick continuous film of
self-pressurized lubricant with no metal-to-metal contact.
Technologically, this is the preferred kind of lubrication
since it offers the lowest coefficient of friction and the
smallest amount of wear.

When the two sliding surfaces are being rubbed to-
gether in the presence of an extremely thin film of lubri-
cant which adheres to both surfaces, this condition is
known as complete boundary lubrication. Unless the
lubricant is renewed periodically, the thin film is even-
tually destroyed and intimate metal-to-metal contact re-

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sults (dry operation) with the result being scoring and
galling of the metals, and eventually seizure.

A transitional zone known as mixed-film lubrication
is a combination of hydrodynamic and boundary lubrica-
tion. Under this condition, part of the total load applied
to an opposing metal surface is supported by individual
load-carrying areas of self-pressurized lubricant and
the remaining part by the very thin film associated with
boundary lubrication.

Under full-film conditions, the coefficient of fluid fric-
tion is approximately proportional to viscosity and speed
and inversely proportional to load. Where true boundary
lubrication exists, the coefficient of friction is independent
of viscosity and rubbing speed. Thus for small values
of ZN/p, where Z is the viscosity of the input fluid, N
is rotational speed and p is bearing pressure (load), the
coefficient of friction remains essentially constant. Be-
tween the boundary and full-film zones of lubrication is
the zone where, with reduction of ZN/p, the coefficient
of friction increases sharply. Evidence indicates that
in this zone a combination of fluid friction and boundary
lubrication exists, i.e., mixed-film lubrication.

When the speed (N) and viscosity (Z) are low, the
load, which can be applied to surfaces without attaining
unduly high coefficients of friction and the resultant
catastrophic effects thereof, must necessarily be very low
Hence, the use of low viscosity fluids as lubricants is
precluded in most industrial applications since their use
places a severe restriction on the load bearing capacity.

Lubrication of the opposing surfaces of seals, gears,
bearings and pistons, therefore, has required the use of
more viscous materials such as hydrocarbon oils, syn-
thetic oils and greases. These lubricants, in addition to
being incapable of being tolerated in certain applications
because of process contamination, possess other disad-
vantages. When these lubricants are used continuously
over extended periods at high pressures and elevated tem-
peratures, they tend to deteriorate. Sludges tend to form
in the lubricants as a result of oxidation, polymerization,
or other causes. These sludges reduce the lubricating
qualities of the lubricant and often cause sticking of
relatively moving parts. In addition, organic acids tend
to form in the lubricant during use thereof, apparently
because of oxidation of the oil at the elevated tempera-
tures to which the oil is exposed, and organic acids
cause corrosion.

Additional disadvantages exist where the operation of
engines require mixing oil with the fuel as in the 2-cycle
engine and the epitrochoidal rotary engines. Smoke,
fouling of the spark plugs, sticking of piston rings, and
carbon deposits result from the use of such mixtures.

It is apparent that great advantages could be obtained
if the process fluid, e.g., gasoline in internal combustion
engines, could itself be used for lubricating the opposing
parts. Besides eliminating the need for auxiliary systems
for handling lubricant, the use of the process fluid for
lubrication could lead to improved reliability and reduc-
tion in the size, weight and cost of the apparatus. Addi-
tionally, since these fluids are being continuously used
up in the operation of the particular process, contamina-
tion by such things as sludge formation would be
minimized.

It is, therefore, the object of this invention to provide
assemblies composed of sleeve bearings, seals, sliding
vanes, pistons, piston rings, etc. moving against opposing
surfaces that will function in the presence of low viscosity
organic agents. It is another object to provide an assembly
capable of converting in situ a low viscosity organic
fluid, e.g., gasoline vapor or liquid, unsuitable as a lubri-
cant in its unpolymerized state to a more viscous polymeric
material characterized by its ability to maintain a state of
boundary lubrication or full-film lubrication during pe-

riods of operation. It is a further object to provide lubricant-producing assemblies for designing and constructing devices (engines, pumps, etc.) in which the problems resulting from the conventional use of lubricants are eliminated.

Summary of invention

The objects are accomplished according to the present invention by an assembly comprising at least two members having relatively movable opposing surfaces, members A and B, and a fluid capable of polymerizing to form a lubricant during operation of the assembly (a lubricant precursor); the metal-opposing surface of member A comprising an alloy selected from the group consisting of (a) an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon and the balance being substantially all iron, and having a Vickers Hardness number of at least 150, (b)[1] an alloy of at least 80 atom percent iron and having a Vickers Hardness number of at least 200, and (c)[1] an alloy of at leart 50 atom percent (50–79 atom percent) iron and having a Vickers Hardness number of at least 400, preferably the alloy of (a) or (b); the metal-opposing surface of member B comprising a mixture of 10–90, preferably 25–60, percent by volume of an alloy of at least 6, preferably at least 12, atom percent of an element selected from the group consisting of molybdenum and tungsten, at least 10 percent, preferably 20–85 percent, by volume of the alloy being an intermetallic compound of said element preferably in the topologically close packed phase, the Vickers Hardness number of the compound being 550–1800, the coefficient of dry friction of the alloy of member B against the surface of member A being no greater than 0.25, and, correspondingly, 90–10 (preferably 75–40) percent by volume of a material having a Vickers Hardness number less than that of the alloy, the strength and adhesive properties of said material being sufficient to support said alloy therein; and the fluid being selected from the group consisting of petroleum hydrocarbons having a terminal boiling point no greater than 345° C., aliphatic alcohols of 1–12 carbon atoms; and aliphatic aldehydes of 4–9 carbon atoms.

It should be understood that the mixture constituting the opposing surface of member B may take the form of particles of the molybdenum or tungsten alloy embedded in a matrix of the softer material to form a composite. The size of the molybdenum or tungsten alloy particles will range from minus 40 mesh to plus 400 mesh.

Specifically, assemblies of this invention can be formed that meet the criteria set forth in the previous paragraphs where one of the relatively movable opposing surfaces comprises a mixture of copper and an alloy of 6–85, preferably 19–25 atom percent molybdenum, 4–56, preferably 4–22 atom percent silicon and the balance essentially 10–90 atom percent of an element selected from the group consisting of iron, cobalt and nickel, preferably 53–77 atom percent cobalt; the other of the relatively movable opposing surfaces comprising an alloy of 1–7 atom percent carbon, up to 13 atom percent chromium and the balance essentially 80–98 atom percent iron; and the fluid selected from the previously stated group but being preferably gasoline. Where the first-mentioned relatively movable opposing surface contains an alloy of tungsten, it may be difficult to incorporate more than 25 atom percent into the alloy because of the high melting point of tungsten.

It should be understood that in addition to molybdenum and tungsten in the one opposing surface and iron in the other opposing surface, amounts of elements other than

[1] Also containing at least 1 atom percent carbon, the sum of any cobalt and nickel being less than 6 atom percent and wherein at least one-half of the weight of the remainder of the alloy is composed of at least one element selected from the group consisting of chromium, manganese, molybdenum and tungsten, said element(s) present as a carbide(s) or in a fully hardened solid solution, e.g., the martensite phase of iron,

those specified above may be used in both surfaces provided that the criteria regarding the Vickers Hardness numbers, intermetallic compound and coefficient of dry friction are met as set forth above. It is also possible to include minor amounts of refractory metal oxides in the alloys used such as those disclosed in U.S. Pat. 3,317,285. In using the system of this invention for sliding elements, performance can be further improved by optimizing the topography, the grooving and the clearance of both surfaces of the sliding couple.

"Coefficient of dry friction," as used in the summary of the invention, is measured in air, as follows:

A test sample of the alloy containing the intermetallic compound used in member B is given a metallographic polish and washed with acetone to insure a smooth clean surface. A ³⁄₁₆-inch ball or, alternatively, an object having a spherical surface (radius of ³⁄₃₂-inch) near its point of contact with the flat surface, composed of the material of member A is cleaned by polishing with 600 grit emery cloth. The test sample of the alloy is mounted on a moving track and passed at a speed of 0.001 cm./sec. in contact with the ball of the member A. A load of 1000 grams is imposed on the ball. The frictional drag created by the sample of the alloy moving in contact with the ball is measured by a tangential strain gauge. The coefficient of dry friction is the tangential force required to move the test sample divided by the normal force, which in this case is 1000 grams.

For purposes of simplicity and clarity in illustrating the critical features of this invention, the discussion will be divided into three segments:

(1) Metal-"contacting" or opposing surface of member B, also referred to as the lubricant producing (LP) surface;

(2) Metal-"contacting" or opposing surface of member A, also referred to as the mating surface; and

(3) Environmental medium, also referred to as the process fluid, carrier fluid or simply, the fluid.

(1) Lubricant producing surface

This surface is a composite of a relatively soft material and the molybdenum or tungsten alloy.

The relatively soft materials may be selected from any of the following four groups. Group (a) includes the metals copper, nickel, aluminum, lead, tin, cadmium and iron. Group (b) includes alloys of the metals of group (a); lead base alloys such as Babbitt (74.5 lead, 10 tin, 15 antimony, 0.5 copper[2]), tin base alloys such as Babbitt (91.2 tin, 4.5 copper, 4 antimony, 0.3 lead[2]), cadmium-base alloys (97.5 cadmium, 1 nickel, 1 silver, 0.5 copper[2]), copper base alloys such as tin bronze (88 copper, 10 tin, 2 zinc[2]), leaded tin bronze (80 copper, 10 lead, 10 tin[2]), and copper-lead (70 copper, 30 lead[2]), aluminum base alloys such as (91 aluminum, 7 tin, 1 copper, 1 silicon[2]), nickel base alloys such as Monel (66 nickel, 31.5 copper, 1.3 iron, 0.9 manganese, 0.1 carbon[2]). Group (c) includes the metals chromium and molybdenum. Group (d) includes phenolic resins and essentially linear resins having a second order transition temperature (as determined by plots of flexural modulus versus temperature) of at least 250° C. and a room temperature modulus of at least 300,000 p.s.i., e.g., phenol-formaldehyde resins, aromatic polyimides, aromatic polyamides, aromatic polyketones, aromatic polythiazoles and polybenzotriazoles.

The important criteria for selecting the molybdenum or tungsten alloy are in three distinct areas: chemical composition; physical structure; and physical characteristics. As for chemical composition, the alloy should contain at least 6 atom percent of molybdenum or tungsten. As for physical structure, it should be composed of at least 10 percent by volume of an intermetallic compound having molybdenum or tungsten as a component,

[2] Parts by weight.

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The physical characteristics should be such that the alloy has a coefficient of dry friction when contacted against the mating surface of no greater than 0.25; the intermetallic compound of the alloy has a Vickers Hardness number ranging between 550 and 1800; and the relatively soft material matrix containing the intermetallic compound should have a Vickers Hardness number less than that of the intermetallic compound.

When used in the present invention, the aforementioned alloys will be capable of producing lubricant when subjected to sliding action in the presence of a fluid capable of being converted into a material having lubricating properties. It is believed that the soft matrix permits particles of the aforementioned alloy to accommodate to any misalignment between surfaces, e.g., shaft and bearing, etc. Thus, superior compatibility and superior results are obtained using the composite. Specifically, when subjected to 50,000 PV (load in p.s.i.×velocity of 180 ft./min. or greater) in the wear tester shown in FIG. 1, the total wear of both lubricant producing surface (sample) and mating surface (reference ring) will be less than 4.0 mils/100 hrs. as measured by micrometer or weight measurements; and the coefficient of friction will be less than 0.2. The test procedure, as set forth hereinafter, was designed so that operating conditions would lead to a state of lubrication below that of the full-fluid range, thus obtaining metal-to-metal interaction. In this way, the compatibility and ability of the metal combinations to produce lubricant can be measured. It is believed that the lubricant is not produced continuously in the system of the invention. Instead, additional lubricant is only produced after that originally formed is used.

It is also observed that the softer matrix, e.g., copper, wears away preferentially, thereby creating cavities at the sliding interface. It is believed that these cavities become filled with the environmental fluid and the lubricant formed. On a micro scale the same phenomenon occurs within the molybdenum or tungsten alloy in that the softer matrix portion is worn preferentially leaving the hard intermetallic compound in relief. It is believed that the environmental fluid and the lubricant formed collect in the micro-cavities which are close enough to provide superior lubrication at the contact points undergoing sliding action.

FIG. 1 is a schematic representation of the wear tester utilized in determining wear performance. It is representative of end thrust type bearings and is useful as a screening device for determining systems of the present invention. The specimen of member A to be tested 12 is rotated by a DC motor 10. The friction between the ring of member B 11 and the test specimen of member A 12 produces a torque in the shaft 13. The shaft 13 is constrained from turning by the lever arm 14 connected to a strain gauge 15. The strain gauge voltage is continuously monitored on a recorder. This voltage is converted into pounds pull by previous calibration. From the geometry of the system, the tangential force on the specimen is calculated. The coefficient of friction equals the tangential force divided by the normal thrust of load pushing the specimen and wear ring together. Wear rates are determined from weight loss and also by micrometer measurements. Tests are carried out by rotating the test specimen at a speed of 180 ft./min. and at varying loads. The PV is determined by multiplying the load in p.s.i. based upon actual contact area by the speed in ft./min.

Specifically, the specimen 12 and the ring 11 are machine ground to obtain parallel faces and then hand lapped on 400 grit paper; vacuum dried at 100° C. for at least 1 hour; and then weighed to 0.0001 gram and measured to 0.0001 inch. They are then mounted in the tester as shown in FIG. 1 and the cup 16 filled with gasoline or other fluid 17. The cup 16 is lined with cooling coils to minimize evaporation. Using only the weight

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of the shaft 13 and lever 14, the tester is run at 650 r.p.m. (to provide 180 ft./min.) for 1 to 2 minutes. After this period, the preselected test load is applied and the test is run continuously for 18 to 20 hours. Due to evaporation, additional fuel must be added every 4 to 6 hours. After 18 to 20 hours, the specimen 12 and the ring 11 are again vacuum dried; weighed; and measured. Alternatively, the tester may be loaded in increments of 20 lbs. while being run at the previously disclosed speed. The tester may be run 30 minutes at each weight increment until failure occurs.

The presence of at least 10 volume percent of an intermetallic compound of molybdenum or tungsten in the contacting surface of member B is vital to the operability of the present invention. These intermetallic compounds, in most cases, occur as an intermediate or secondary phase within a solid solution or matrix phase. They vary in amount and size and are of diverse types. The amount and type is determined by such factors as the particular chemistry of the metals being alloyed, the length of time at which the alloy is subjected to specific temperature conditions, and the cooling rate. Intermetallic compounds found in the alloys operable in this invention include (1) the topological close packed (TCP) structures including the sigma, chi, mu and Laves phases, (2) the semi-carbides of the M_6C and $M_{23}C_6$ type and (3) Mo Si_2 type. The presence and amount of intermetallic compounds may be determined by either X-ray diffraction or metallographic analysis.

Of primary interest for this invention are the intermetallic compounds of Laves phase structures characterized by the ternary phase systems, Co-Mo-Si, Ni-Mo-Si, Co-W-Si and Ni-W-Si. These alloys are disclosed in U.S. Pat. 3,257,178 to Severns and Smith and represent the most desirable alloys for use as the metal-opposing surface of member B. Specifically, these alloys are defined in this patent as consisting essentially of a substantial amount of at least one metal A and a substantial amount of at least one metal B, and silicon, metal A being selected from the group consisting of molybdenum and tungsten and metal B being selected from the group consisting of cobalt and nickel; and sum of the amounts of metals A and B being at least 60 atom percent of the alloy; the amount of silicon and the relative amounts of metals A and B being such as to provide 30–85 volume percent of said alloy in the Laves phase; the Laves phase being distributed in a relatively soft matrix of the remaining 70–15 volume percent of said alloy.

(2) Mating surface

The important criteria for selecting the material for the mating surface of member A are in two distinct areas: chemical composition and physical characteristics. The particular materials may be divided into three groups, the first two being preferred.

The first group embraces the cast irons containing graphite. They are the gray cast irons and malleable cast irons. Carbon content varies from 11 to 15 atom percent, and silicon content from 1.5 to 3 atom percent with the balance being iron and trace amounts of other metals. Hardnesses can be as low as Vickers Hardness number of 150. It is believed that the presence of the carbon as graphite offsets the effect of softness. These alloys are useful as piston rings, cylinder walls and in other applications having poor lubrication.

The second group consists of iron alloys containing at least 80 atom percent iron, at least 1 atom percent carbon and having Vickers Hardness numbers of at least 200. This group embraces the white cast irons, carbon steels, most of the tool steels and the bottom of the range of martensitic stainless steels. It is preferred that the Vickers Hardness number of the steels in this group be over 270.

The third group consists of iron-base alloys containing 50–79 atom percent iron, at least 1 atom percent carbon and having Vickers Hardness numbers of at least 400.

Also undesirable are the ferritic stainless steels and most of the austenitic stainless steels. However, it may be possible to use work hardened low nickel alloys of austenitic stainless steels.

The major alloying element for the second and third groups are chromium, manganese, molybdenum and tungsten. These elements should represent at least one-half of the weight of the remaining alloying elements (besides iron and carbon) and should be present primarily as carbide precipitates or in a fully hardened solid solution, e.g., the martensite phase of iron. Nickel and cobalt are undesirable and their sum in the alloy should be less than 6 atom percent.

(3) Environmental medium

The most impressive feature of the system of this invention is its ability to polymerize certain fluids to form lubricants in situ, thereby obviating the necessity of using an extraneous (non-essential to the function of the system) material such as heavy petroleum products (e.g., motor oils, lubes, and greases). Because of their commercial interest, the invention is concerned primarily with systems involving petroleum hydrocarbon fuels as the environmental medium. Thus, gasoline in automotive, marine, and aircraft engines; kerosene and jet fuels in modern jet aircraft; and diesel fuels in diesel type engines are particularly useful in this invention. These fluids may be classified as petroleum hydrocarbons whose terminal boiling points are no greater than 345° C. The fluids may be used in liquid or vapor form. One method to achieve the results of the present invention is to spray gasoline vapor into the chamber containing the relatively movable opposing surfaces.

It should be noted that as little as 10 weight percent of a fluid operable in this invention in combination wtih 90 weight percent of an inoperable fluid will operate successfully as part of the system of this invention. It should also be pointed out the systems of this invention will operate in the presence of conventional lubricants (solid or fluid) and hydraulic fluids and will thus make possible the use of lesser quantities of such added lubricant. Furthermore, the systems of this invention could permit the use of mixtures or dispersions of the specified hydrocarbons, alcohols and aldehydes with such fluids as trichloroethylene, water, etc. which are not usually considered lubricants. The use of the systems of this invention make it possible to use hydraulic fluids of relatively low viscosity. During operation, the viscosity of the lubricants produced from these fluids is high enough to perform a lubricating function. In cold weather operation, the viscosity of the hydraulic fluid is low enough so that no heating is required to maintain fluidity as is usually necessary with more viscous fluids.

USES OF THIS INVENTION

The assemblies of this invention find applicabilitiy in all types of engines: 2- and 4-cycle reciprocating engines; 2- and 4-cycle rotary engines including the epitrochoidal, elliptical, wedge and vane piston types; free piston gas generating engines; turbo-jet engines; standard jet engines; and gas turbine engines. Thus, in a 2-cycle reciprocating engine, the bearing surfaces and seals can be composed of or coated with a composite of copper and the alloy of molybdenum or tungsten referred to herein as member B; while the opposing surfaces including the crankshaft, the piston cylinder wall, etc. can be composed of the alloy of iron referred to herein as the member A alloy.

The assemblies are also useful in fuel pumps and fuel injectors. Thus, in the fuel injectors the member B composite can be used as a surface coating for the plunger which slides through a chamber made of member A, or member B can be used as a coating for the cylinder chamber through which a plunger made of or coated with member A slides. In a fuel pump, the vanes can be coated with or composed of the member B composite which

makes "contact" with a chamber of member A, or vice versa. This permits operation with low viscosity fuels such as gasoline or kerosene. This opens up the possibility of operating diesel engines with less viscous fuels than are now used.

A particularly interesting application of the present invention is in the rotary internal combustion engine described in U.S. Pat. 3,359,953. This patent describes special techniques to overcome the side sealing problem. The member B composite of the present invention has been used on the "contacting" surface of the end face seals while the inner surfaces of the end walls were composed of member A alloy.

Another interesting application of the present invention is as a solution to the problem of increasing the load bearing capacity of oil impregnated porous bearings, i.e., self-lubricating bearings. Relatively large pores are needed in these bearings to transmit the relatively viscous lubricant, thereby reducing load bearing capacity. By using a low viscosity precursor that forms a high viscosity lubricant in situ on the bearing surface, smaller pores would be used. This, in turn, increases the load bearing capacity of the bearing. By using the member B composite in the bearing along with the environmental media set forth for this invention, greases having greater viscosity than conventional oils are produced with an accompaning increase in load bearing capacity.

To summarize, the assemblies of this invention will be useful in a multitude of situations involving the use of bearings, gears, seals and pistons, the members of the assemblies being used either to form the parts or as coatings for such parts. The following listing of uses is not intended to be limitative but intended to appraise those skilled in the art of useful applications of this invention.

LISTING OF END USES

I. General bearings

(A) Journal bearings:
   (1) Bushings
   (2) Wick-oil
   (3) Oval-ring
   (4) Pressure-fed
   (5) Circumferential groove
   (6) Cylindrical
   (7) Cylindrical overshot
   (8) Pressure
   (9) Multiple-groove
   (10) Elliptical
   (11) Three-lobe
   (12) Pivoted shoe
   (13) Partial
   (14) Externally pressurized
(B) Thrust bearings:
   (1) Flat-land
   (2) Tapered land
   (3) Pivoted shoe
   (4) Step
   (5) Externally pressurized
   (6) Pocket
   (7) Standardized bushings
   (8) Slewing rings

II. Specific bearings

(1) Internal combustion engines—reciprocating
(2) Internal combustion engines—rotary (epitrochoidal, elliptical, wedge, vane piston)
(3) Liquid handling pumps, stirrers, and other chemical processing equipment
(4) Hydraulic equipment
(5) Vacuum pumps
(6) Turbine engines
(7) Jet engines
(8) Refrigerating equipment

(9) Stirling cycle (heat) engine
(10) Gas compressors

III. Specific gears

(1) Transmissions—automotive, farm machinery
(2) Milling machinery
(3) Lathes
(4) Differentials
(5) Gear reducers
(6) Planetary
(7) High speed quills
(8) Splines
(9) Cams
(10) Worms
(11) Chain drives
(12) High speed slides

IV. Seals

(1) Rotary engines
(2) Piston rings—Internal combustion engines
(3) Chemical pumps
(4) Fuel pumps

V. Pistons

(1) Internal combustion engines
(2) Hydraulic equipment
(3) Fuel injectors and pumps
(4) Positive displacement type fuel pumps

It should be noted that in using this system for sliding elements, e.g., seals, journal bearings, etc., performance can be improved by optimizing the topography, the grooving and the clearance of both opposing surfaces of the sliding couple.

The present invention is further illustrated by the following examples.

EXAMPLE 1

A composite was prepared by mixing —100 mesh copper powder with —100 +200 mesh alloy[3] of cobalt, molybdenum and silicon in the ratio of 50/50 percent by volume. The mixture was plasma sprayed onto an aluminum substrate. The composite was then tested in the wear tester shown in FIG. 1 against 1095 steel[4] hardened to a Vickers Hardness number of 510. A PV of 140,000 was applied to the test specimen and the tester was run for 6 hours in an environment of gasoline. The gasoline was introduced into the tester in the form of a spray at a flow rate of 0.42 ml./min. The coefficient of friction was measured and found to be 0.08. At the end of the 6-hour run, the test specimen and the mating surface were examined. Not only was there substantially little or no wear evidenced, but also an amber colored product resembling grease was found to be present at the interface of contacting surfaces. The average cryoscopic molecular weight of this reaction product was found to be 420, contrasting with an average molecular weight of 107 for the gasoline initially introduced.

The lubricity of the reaction product was then measured and compared with that of commercially available grease. A small amount of the reaction product was rubbed on a specimen made from 1020 cold rolled steel.[5] This specimen was then placed in the wear tester and brought into contact with a reference ring of 1095 steel (Vickers Hardness number=510). The combination of 1095 steel against 1020 steel would normally seize immediately in a gasoline environment. In the presence of the reaction product, however, which was smeared on the surface interface between the two steels, the tester ran smoothly at a PV of 200,000; the wear rate was low; and the coefficient of friction was 0.036, identical to that obtained when a commercial grade lubricating grease was employed. In contrast, when vaseline, a less effective lubricant was substituted, the coefficient of friction increased to 0.08 at a PV of only 55,000. The measured wear rate was correspondingly high.

EXAMPLES 2–8

A series of iron alloys as member A and composites of various matrix materials and alloys of molybdenum or tungsten as member B was prepared and tested in the wear tester shown in FIG. 1 following substantially the procedure set forth in Example 9. Gasoline was used as the environmental medium in Examples 2–6; n-octane, in Example 7 and hexanol, in Example 8.

The alloy used as member A and its Vickers Hardness number (V.H.) and the composite used as member B are shown in Table I–A and the results are shown in Table I–B.

TABLE I–A

Member A	Member B, alloy—matrix material (volume percent)
Example:	
2_____ 1095 steel [a]____	20 CM 5535 [b]—60 copper, 20 nickel.
3_____ Elastuff 44 [c]___	40 CM 5535—60 nickel.
4*_____do_____	25 CM 5535—75 polyimide. [d]
5_____ 1095 steel_____	20 NW 4540 [e]—80 copper.
6_____ C 610 [f]_____	35 CM 5535—65 copper.
7_____ 1095 steel_____	35 NW 4540—65 copper.
8_____ Elastuff 44____	35 CM 5535—65 copper. _____

[a] 95.7 at. percent Fe, 4.3 at. percent C (V.H. 516).
[b] 56.4 at. percent Co, 22.1 at. percent Mo, 21.5 at percent Si
[c] 93.6 at. percent Fe, 2.1 at. percent C, 1.7 at. percent S, 1 at. percent Cr, 0.9 at. percent Mn, 0.4 at. percent Si, 0.3 at. percent Mo (V.H. 434).
[d] polymer of 4,4'-oxydianiline and pyromellitic dianhydride.
[e] 50.7 at. percent Ni, 14.5 at. percent W, 34.8 at. percent Si.
[f] 80 at. percent Fe, 12 at. percent Cr, 6.6 at. percent C, 1 at. percent V, 0.4 at. percent Mo (V.H. 720).
* Cold pressing and heated to a temperature of 200–500° C.

TABLE I–B

Example	PV × 1,000	Coefficient of friction	Total wear (mils/100 hrs.) Mem. A	Total wear (mils/100 hrs.) Mem. B
2_____	164	0.11	0.0	0.2
3_____	57	0.17	0.0	0.0
4_____	57	0.04	0.0	0.0
5_____	100	0.05	0.1	0.5
6_____	90	0.16	0.0	0.7
7_____	55	0.1	0.0	0.4
8_____	70	0.07	0.0	0.0

EXAMPLE 9

FIG. 2 illustrates a device utilized to test the efficiency of certain type bearings intended for commercial applications. Referring to this schematic sketch, friction between shaft 61 and the bearing to be tested 62 causes a yolk 63 to rotate when a load 64 is applied. The rotation of the yolk applies a force to a torque transducer 65 through lever arm 66. From the torque which is recorded on a chart recorder, not shown, the tangential force acting at the bearing shaft interface is calculated. This divided by the load applied gives the coefficient of friction. The transducer is calibrated before each test. The process fluid, is introduced into the bearing system through port 67.

The test procedure involves increasing the flow of gasoline to 1 lb. per hour at no load and then increasing the "r.p.m." of the shaft to the desired level. The load is applied in increments of 20 lb. and the apparatus allowed to run from 30 minutes to an hour at each step.

A composite was prepared by pressing —100 mesh copper powder with 28 volume percent of an alloy consisting of 56 atom percent cobalt, 22 atom percent molybdenum and 22 atom percent silicon (—100 mesh +200 mesh). After heating the composite to 850° C. in hydrogen, billets were forged in air to a diameter of 1¼ inches. After heat treatment at 850° C. in hydrogen for 3–4 hours to promote bonding between copper and the alloy, journals were rough machined using carbide tools to within 10

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[3] 56 atom percent cobalt, 22 atom percent molybdenum and 22 atom percent silicon.
[4] 95.7 atom percent iron, 4.3 atom percent carbon.
[5] 0.9 atom percent carbon, 0.5 atom percent manganese, 98.6 atom percent iron (all nominal).

mils of final tolerances and then ground to the final diameter of the journal bearings, 0.750 inch.

As Control A, the journal bearings were fabricated by casting the above-mentioned cobalt molybdenum-silicon alloy alone.

As Control B, journal bearings were fabricated from bronze SAE 660.[6]

The bearings were all tested in the device shown in FIG. 2 using gasoline as the fluid and a shaft of hardened steel, SAE 52100[7] and a shaft speed of 1200 revolutions per minute. The results at various loadings are shown in the following table:

TABLE II.—COEFFICIENT OF FRICTION AT VARIOUS LOADINGS (PV)

	PV (p.s.i. × ft./min.)				
	10,000	25,000	50,000	75,000	100,000
Example 9		0.004	0.006	0.007	0.004
Control A		0.21	0.16	0.16	0.16
Control B	Seized	Seized	Seized	Seized	Seized

EXAMPLE 10

A 2-cycle engine was modified as shown in FIG. 3 to permit operation without addition of oil to the fuel system. The original engine was a 2-cycle, 2½ horsepower engine Model D-402 manufactured by the Outboard Marine Corp., Galesburg, Ill. The clearances after modifications of the bearings, piston, and piston rings were the maximum allowable falling within the specifications of the manufacturer. In addition, the sleeve bearings were grooved to direct the gasoline to the bearing interfaces.

The sleeve bearings 21 and 22 used as magneto plate-bearings and shaft bearings were made from composites of copper and 28 percent by volume of the alloy[8] used in Example 1. These bearings were sealed at both ends to prevent gasoline from passing directly into the aluminum crankcase. A hardened low alloy steel within the definition of member A of the invention was used as the crankshaft 24. The piston 29 was coated with a mixture of copper and 25 percent by volume of the allow of Example 1 by plasma spraying to a thickness of .004–.005 inch. The particular size used in these coatings was —100 mesh and 200 mesh. A band of this coating was put at the top and bottom of the piston, although it is preferable to coat the entire piston. This piston rings 28 which slide against the cast iron cylinder walls were the manufacturer's cast iron rings coated with the alloy of Example 1 by plasma spraying.

Although the fuel pump was electrically operated, it may be operated as a positive displacement diaphragm-type fuel pump as shown in FIG. 3. The flow of fuel (gasoline) is designated by the dotted lines. Fuel from the tank 31 is sucked into the fuel pump 30. From here, it is pumped into bearing 22, removed from a port on the opposite side, and passed into the cast-iron cylinder 32 through port 33 and other similar orthogonal ports not shown. The fuel flowing into port 33 lubricates bearings 26 and 27 in the following manner. Hollow wrist pin 25 is blocked at one end to prevent fuel from passing through it and out the exhaust port 34. When the wrist pin 25 passes over the port 33, gasoline is ejected into it and flows towards the exhaust end. Since this end is blocked and bearings 26 and 27 are provided with openings, this gasoline flows into these bearings for lubrication. Not shown in FIG. 3 are the openings in the bottom of bearing 27 and in the top of bearing 26 to allow

gasoline vapor in the crankcase 36 to provide additional lubrication to bearings 26 and 27.

Fuel may also be pumped from pump 30 into bearing 21. It then flows down this bearing as indicated and through and opening 35 in the crankshaft 24 to lubricate bearing 23. Bearing 23 is a roller bearing having an outer race of an alloy (77 atom percent cobalt, 19 atom percent molybdenum and 4 atom percent silicon). The crankshaft served as an inner race and the manufacturer's needles (52100 steel)[9] were used as rolling elements.

The fuel is ejected from bearing 23 into the crankcase chamber 36. Fuel is also pumped into the carburetor 37. The reed valve 38 on the carburetor closes when the crankcase 36 is under compression and opens when the crankcase is under a low pressure, i.e., when the piston 39 is in its highest position. Although not shown on the figure, there are ports for channeling the gasoline-air mixture into the combustion chamber 40. Flow of fuel through the carburetor 37 is controlled by the amount of air sucked into the engine. This amount of air, in turn, is controlled by a governor.

It was found that for smooth engine operation it was desirable that at least 50 percent of the fuel passed through the normal combustion route, i.e., through the carburetor and into the combustion chamber on the upstroke of the piston. The control of the amount of flow of gasoline through the carburetor 37 and to bearings 21, 22 and 23 is accomplished by needle valves.

In the test run, the pump 30 was started to admit fuel to all bearing surfaces just prior to starting the engine. Thus, the bearings were not operated in the dry condition. The engine was then run for 50 hours using commercially available permium gasoline containing no oil. The fuel was introduced into the engine at a rate of 2.1 lbs./hr. The air flow was 19 lbs./hr. giving an air-fuel ratio of about 9 to 1. The engine speed was 2,450 r.p.m. No load was placed on the engine. During operation, there was no visible smoke in the exhaust as occured during operation of the unmodified 2-cycle engine run on the fuel-oil mixture recommended by the manufacturer. Other than a thin sooty deposit that covered piston and cylinder walls, there were no engine deposits. The dimensions of the essential friction wear parts were measured before and after the test to determine the amount of wear. The results are tabulated in Table III.

TABLE III.—DIMENSIONS OF ESSENTIAL FRICTIONWEAR PARTS BEFORE AND AFTER 50 HOUR ENGINE TEST

Wear part	Dimensions before testing (inches)	After testing (inches)	Total wear (inches)
Magneto plate-bearing 22	0.8772	0.8772	0.0000
Lower bearing 21	0.8771	0.8771	0.0000
Shaft magneto bearing 22	0.8744	0.8742	0.0002
Shaft lower bearing 21	0.8743	0.8741	0.0002
Piston 29	2.3710	2.3710	0.0000
Cylinder 32	2.3770	2.3770	0.0000

Where engine designs are such that oil must be present to insure lubrication of certain surfaces, it is possible by use of the lubricant-producing surfaces of this invention to greatly reduce the amount of oil that must be supplied. For example, the 2-cycle engine described above has been run, without introducing fuel through the cylinder wall, by using instead of the pure gasoline a mixture of 1 part of SAE 30 oil in 500 parts of gasoline. With the usual sliding surfaces in the combustion chamber a ratio of 1 part of standard oil in 16 parts of gasoline is required.

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[6] 90 atom percent copper, 4 atom percent tin, 4 atom percent zinc, and 2 atom percent lead.

[7] 93.2 atom percent iron, 4.4 atom percent carbon, 1.5 atom percent chromium, 0.6 atom percent silicon, 0.3 atom percent manganese.

[8] 56 atom percent cobalt, 22 atom percent molybdenum and 22 atom percent silicon.

[9] 93.2 at. percent Fe, 4.4 at. percent C, 1.5 at. percent Cr, 0.6 at. percent Si, 0.3 at. percent Mn.

When a completely unmodified 2-cycle engine of a similar design was run on a gasoline-oil (16–1 ratio) mixture for 32 hours, the exhaust ports were almost completely clogged with heavy deposits of carbon. Further running of this engine would require disassembly and cleaning of ports, piston and cylinder.

EXAMPLE 11

One of the most promising potential end uses for the present invention would appear to be as seals in rotary engines. A sequence of tests to evaluate the performance of the system of this invention as seals in the engine described in U.S. Pat. 3,359,953 (the Wankel engine) was initiated. For this, a Gast air motor was used, as illustrated in FIG. 4. Normally, this engine would be powered by compressed air injected through the inlet. For these experiments, however, the motor was driven by means of bearing tester described for use in FIG. 2. The motor of the bearing tester was attached to the rotary shaft of the air motor by a coupling causing the air motor to rotate.

In the first test, vanes 51 made from a composite of copper and 30 percent by volume of the alloy of Example 1 were compared to hard chromium plated vanes. The test was run at room temperature. The motor was driven at 1200 r.p.m. while 0.1 lb. per hour of commercially available premium grade gasoline was flushed through it with 1 lb. per hour of nitrogen. This low amount of gasoline was used to more closely simulate the amount of unburned fuel in an engine. In a 3.5 hour run the chromium plated vanes ruined the cast-iron housing and generated enough wear debris to plug the outlet port. In the same period, no wear of the vanes or housing could be measured when the vanes were made from the composite described in Example 9. Next, the test on the vanes of this composite was repeated except that the housing was heated to 150° C., the highest surface temperature reached in the Wankel engine.[10] Again, no wear of the composite vanes or housing could be measured. After the test all interior surfaces were coated with a substance corresponding in viscosity to SAE 20–30 grade commercial oil, indicating formation of a lubricant in situ when in continuous contact with gasoline.

EXAMPLE 12

To demonstrate a gasoline pump using the system of this invention, the vanes in a Gast air motor were replaced with vanes prepared from the composite set forth in Example 11. The motor was operated as a pump by driving it with bearing tester of FIG. 2 at 1200 r.p.m. Gasoline was pumped at a rate of 30 gal./hr. in a closed loop with a one gallon reservoir for 5.25 hours. No wear on the vanes could be measured and the weight loss per vane averaged one milligram.

[10] Wankel engine using an aluminum housing.

What is claimed is:

1. A system comprising an assembly of at least two members, members A and B, having relatively movable opposing surfaces and an environmental fluid capable of forming a lubricating medium for said opposing surfaces during operation of the assembly; the opposing surface of member A consisting essentially of an alloy selected from the group consisting of (a) an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon and the balance being substantially all iron, and having a Vickers Hardness number of at least 150, (b) an alloy of at least 80 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 200, and (c) an alloy of 50–79 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 400, the sum of any cobalt and nickel in said alloys (b) and (c) being less than 6 atom percent, at least one-half of the weight of the remainder of alloys (b) and (c) being selected from the group of elements consisting of chromium, molybdenum, manganese and tung-

sten, said element(s) being present as carbide(s) or in a fully hardened solid solution; the opposing surface of member B consisting essentially of a mixture of 10–90 volume percent of an alloy of at least 6 atom percent of an element selected from the group consisting of molybdenum and tungsten, at least 10 percent by volume of said alloy being an intermetallic compound of said element, the Vickers Hardness number of said compound being 550–1800, the coefficient of dry friction of said alloy of member B against the surface of member A being no greater than 0.25 and, correspondingly, 90–10 percent by volume of a material having a Vickers Hardness number less than that of said alloy, the strength and adhesive properties of said material being sufficient to support said alloy therein; and said environmental fluid being selected from the group consisting of petroleum hydrocarbons having a terminal boiling point no greater than 345° C., aliphatic alcohols of 1–12 carbon atoms and aliphatic aldehydes of 4–9 carbon atoms.

2. A system as in claim 1 wherein said opposing surface of member A is an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon, the balance being substantially all iron, having a Vickers Hardness number of at least 150.

3. A system as in claim 1 wherein said opposing surface of member A is said alloy of at least 80 atom percent iron having a Vickers Hardness number of at least 200.

4. A system as in claim 1 wherein the alloy of the mixture in the opposing surface of member B is an alloy of at least 12 atom percent of an element selected from the group consisting of molybdenum and tungsten.

5. A system as in claim 4 wherein said element is molybdenum.

6. A system as in claim 4 wherein said element is tungsten.

7. A system as in claim 1 wherein the alloy of the mixture in the opposing surface of member B consists essentially of 6–85 atom percent molybdenum, 4–56 atom percent silicon, the balance being selected from the group consisting of iron, cobalt and nickel.

8. A system as in claim 1 wherein the alloy of the mixture in the opposing surface of member B consists essentially of 19–25 atom percent molybdenum, 4–22 atom percent silicon and 53–77 atom percent cobalt.

9. A system as in claim 1 wherein the intermetallic compound in the alloy of said opposing surface of member B is 20–85 percent by volume of the alloy.

10. A system as in claim 1 wherein said environmental fluid is a petroleum hydrocarbon having a terminal boiling point no greater than 345° C.

11. A system as in claim 1 wherein said environmental fluid is gasoline.

12. A system as in claim 14 wherein said environmental fluid is gasoline.

13. A system as in claim 1 wherein oil is added to said environmental fluid.

14. A system as in claim 1 wherein said material in the mixture having a Vickers Hardness number less than that of said alloy is selected from the groups consisting of (a) copper, nickel, aluminum, lead, tin, cadmium and iron, (b) alloys of the metals of group (a), (c) chromium and molybdenum, and (d) polyimides, aromatic polyamides, aromatic polyketones, polybenzimidazoles, aromatic polyimines, polybenzotriazoles, aromatic polythiazoles, phenol-formaldehyde resin.

15. A system as in claim 1 wherein said material is copper.

16. A system as in claim 1 wherein said material is a copper alloy.

17. A system as in claim 1 wherein said material is nickel.

18. A system as in claim 1 wherein said material is a polyimide of pyromellitic dianhydride and 4,4′ oxydianiline.

19. An assembly comprising at least two members,

members A and B, having relatively movable opposing surfaces; the opposing surface of member A consisting essentially of an alloy selected from the group consisting of (a) an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon and the balance being substantially all iron, and having a Vickers Hardness number of at least 150, (b) an alloy of at least 80 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 200, and (c) an alloy of 50–79 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 400, the sum of any cobalt and nickel in said alloys (b) and (c) being less than 6 atom percent, at least one-half of the weight of the remainder of alloys (b) and (c) being selected from the group of elements consisting of chromium, molybdenum, manganese and tungsten, said element(s) being present as carbide(s) or in a fully hardened solid solution; and the opposing surface of member B consisting essentially of a mixture of 10–90 volume percent of an alloy of at least 6 atom percent of an element selected from the group consisting of molybdenum and tungsten, at least 10 percent by volume of said alloy being an intermetallic compound of said element, the Vickers Hardness number of said compound being 550–1800, the coefficient of dry friction of said alloy of member B against the surface of member A being no greater than 0.25, and, correspondingly, 90–10 volume percent of a material having a Vickers Hardness number less than that of said alloy, the strength and adhesive properties of said material being sufficient to support said alloy therein.

20. An assembly as in claim 19 wherein said opposing surface of member A is an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon, the balance being substantially all iron, having a Vickers Hardness number of at least 150.

21. An assembly as in claim 19 wherein said opposing surface of member A is said alloy of at least 80 atom percent iron having a Vickers Hardness number of at least 200.

22. An assembly as in claim 19 wherein the alloy of the mixture in the opposing surface of member B is an alloy of at least 12 atom percent of an element selected from the group consisting of molybdenum and tungsten.

23. An assembly as in claim 22 wherein said element is molybdenum.

24. An assembly as in claim 22 wherein said element is tungsten.

25. An assembly as in claim 19 wherein the alloy of the mixture in the opposing surface of member B consists essentially of 6–85 atom percent molybdenum, 4–56 atom percent silicon, the balance being selected from the group consisting of iron, cobalt and nickel.

26. An assembly as in claim 19 wherein the alloy of the mixture in the opposing surface of member B consists essentially of 19–25 atom percent molybdenum, 4–22 atom percent silicon and 53–77 atom percent cobalt.

27. An assembly as in claim 19 wherein the intermetallic compound in the alloy of said opposing surface of member B is 20–85 percent by volume of the alloy.

28. An assembly as in claim 19 wherein said material in the mixture having a Vickers Hardness number less than that of said alloy is selected from the groups consisting of (a) copper, nickel, aluminum, lead, tin, cadmium and iron, (b) alloys of the metals of group (a), (c) chromium and molybdenum, and (d) polyimides, aromatic polyamides, aromatic polyketones, polybenzimidazoles, aromatic polyimines, polybenzotriazoles, aromatic polythiazoles, phenol-formaldehyde resin.

29. An assembly as in claim 19 wherein said material is copper.

30. An assembly as in claim 19 wherein said material is a copper alloy.

31. An assembly as in claim 19 wherein said material is nickel.

32. An assembly as in claim 19 wherein said material

is a polyimide of pyromellitic dianhydride and 4,4' oxydianiline.

33. A process for forming a lubricating medium which comprises placing the surfaces of at least two members, members A and B, in opposition, the opposing surface of member A consisting essentially of an alloy selected from the group consisting of (a) an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon and the balance being substantially all iron, and having a Vickers Hardness number of at least 150, (b) an alloy of at least 80 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 200, and (c) an alloy of 50–79 atom percent iron, at least 1 atom percent carbon, and having a Vickers Hardness number of at least 400, the sum of any cobalt and nickel in said alloys (b) and (c) being less than 6 atom percent, at least one-half of the weight of the remainder of alloys (b) and (c) being selected from the group of elements consisting of chromium, molybdenum, manganese and tungsten, said element(s) being present as carbide(s) or in a fully hardened solid solution; and the opposing surface of member B consisting essentially of a mixture of 10–90 volume percent of an alloy of at least 6 atom percent of an element selected from the group consisting of molybdenum and tungsten, at least 10 percent by volume of said alloy being an intermetallic compound of said element, the Vickers Hardness number of said compound being 550–1800, the coefficient of dry friction of said alloy of member B against the surface of member A being no greater than 0.25, and, correspondingly, 90–10 percent by volume of a material having a Vickers Hardness number less than that of said alloy, the strength and adhesive properties of said material being sufficient to support said alloy therein; adding a fluid in a manner such that it flows onto the opposing surfaces of members A and B, said fluid being selected from the group consisting of petroleum hydrocarbons having a terminal boiling point no greater than 345° C., aliphatic alcohols of 1–12 carbon atoms and aliphatic aldehydes of 4–9 carbon atoms; and moving said opposing surfaces relative to each other whereby said fluid is polymerized to form a lubricating medium.

34. A process as in claim 33 wherein an oil is added with said fluid.

35. In a lubricating system composed of the opposing surfaces of at least two members, members A and B, and a lubricating fluid present on said opposing surfaces, the improvement wherein the opposing surface of member A consists essentially of an alloy selected from the group consisting of (a) an alloy of 11–15 atom percent carbon, 1.5–3 atom percent silicon, the balance being substantially all iron, having a Vickers Hardness number of at least 150, (b) an alloy of at least 80 atom percent iron and having a Vickers Hardness number of at least 175, and (c) an alloy of at least 50 atom percent iron and having a Vickers Hardness number of at least 400, the sum of any cobalt and nickel in said alloys (b) and (c) being less than 6 atom percent, at least one-half of the weight of the remainder of alloys (b) and (c) being selected from the group of elements consisting of chromium, molybdenum, manganese and tungsten, said element(s) being present as carbide(s) or in a fully hardened solid solution; and the opposing surface of member B consists essentially of a mixture of 10–90 volume percent of an alloy of at least 6 atom percent of an element selected from the group consisting of molybdenum and tungsten, at least 10 percent by volume of said alloy being an intermetallic compound of said element, the Vickers Hardness number of said compound being 550–1800, the coefficient of dry friction of said alloy of member B against the surface of member A being no greater than 0.25, and, correspondingly, 90–10 percent by volume of a material having a Vickers Hardness number less than that of said alloy, the strength and adhesive properties of said material being sufficient to support said alloy therein.

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