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Calabrese

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[54] **WEAR RESISTANT FRICTIONALLY CONTACTING SURFACES**

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[52] **U.S. Cl.** **308/241**, 417/DIG. 1, 418/179
[51] **Int. Cl.** **F16c 33/12**
[58] **Field of Search** 418/177, 179; 308/8, 241; 417/DIG. 1

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Primary Examiner—C. J. Husar
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[57] **ABSTRACT**

An improved mechanical system comprising a first part presenting an aluminum surface, a second part presenting a second surface capable of being in sliding contact with the aluminum surface, and means for inducing and maintaining the two surfaces in sliding contact with each other, for example, an hydraulically operated piston-cylinder mechanical system, the improvement consisting of employing as the second surface a metallic surface comprising an alloy containing at least 60 atom percent of at least two heavy metal transition elements, the ratio of the atomic radii of the largest to the smallest transition elements being 1.05–1.68, and consisting of 10–100 volume of a hard phase and 0–90 volume percent of a matrix phase which is softer than the hard phase, said hard phase containing a major fraction of Laves phase in such amount as to provide at least 10 volume percent thereof in the alloy.

10 Claims, 6 Drawing Figures

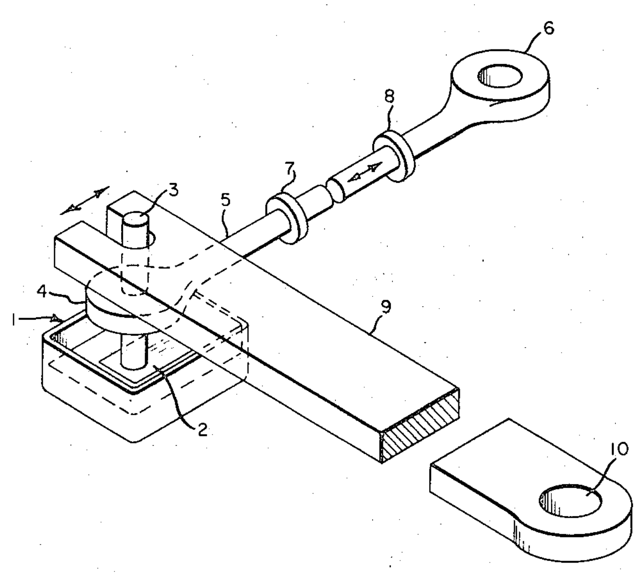


FIG. 1

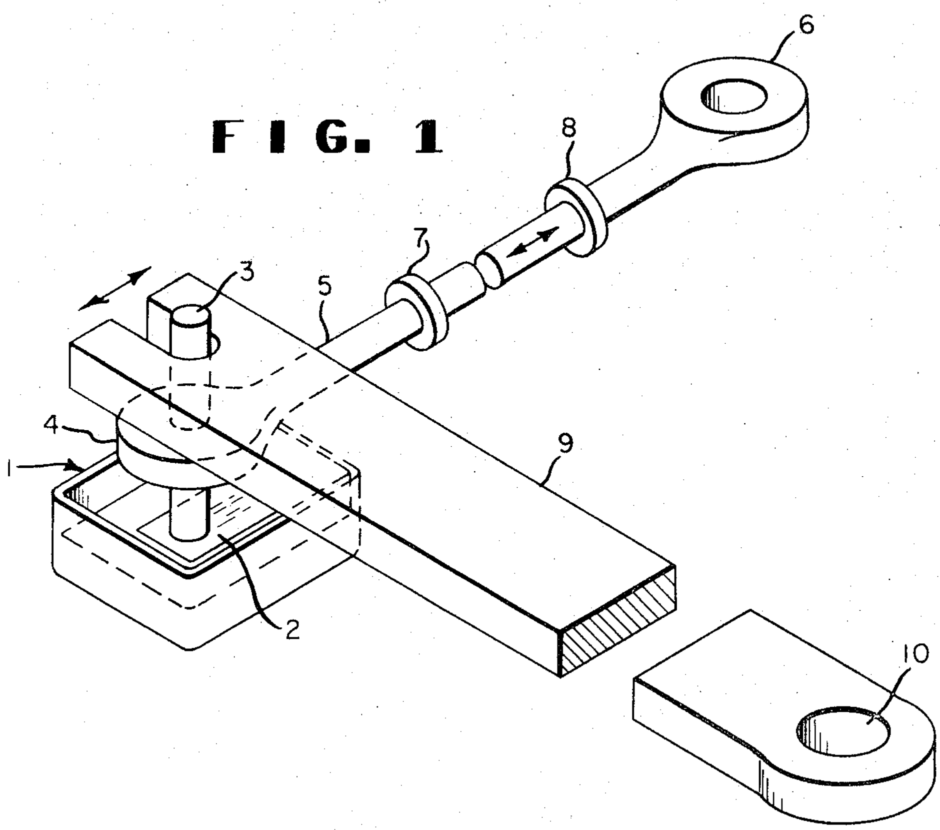


FIG. 2

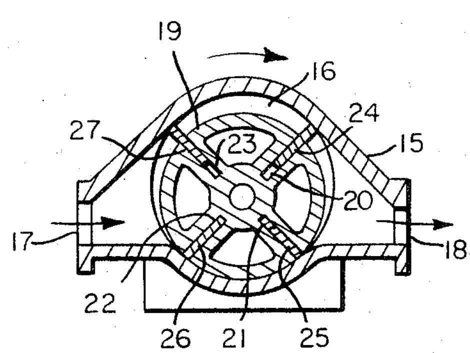


FIG. 3

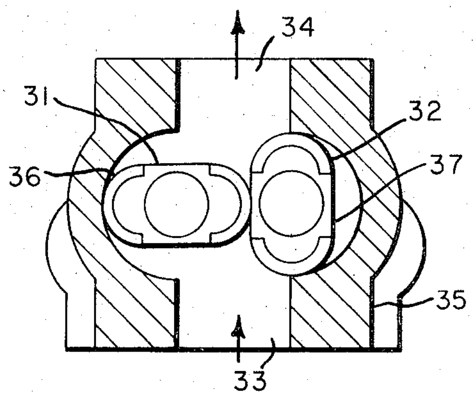


FIG. 4

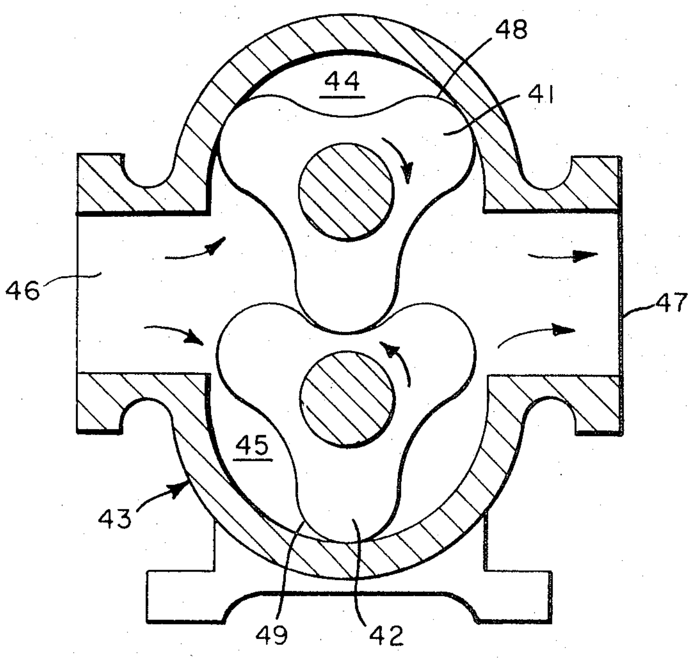


FIG. 5

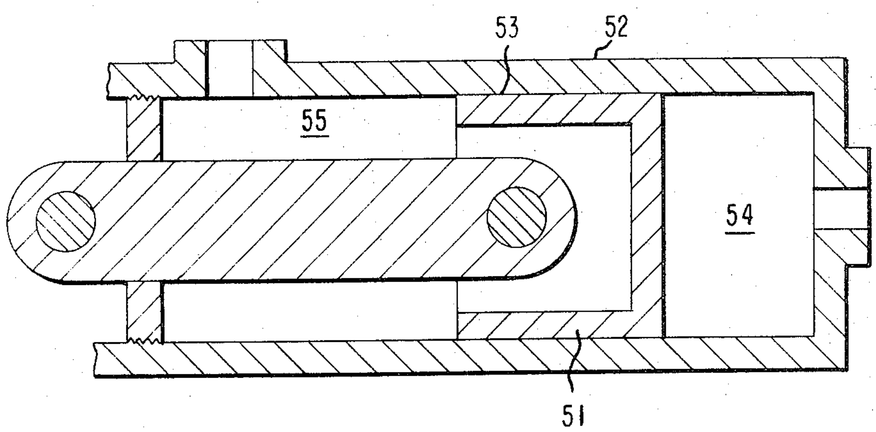
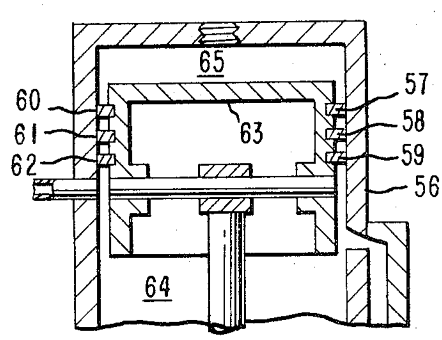


FIG. 6



WEAR RESISTANT FRICTIONALLY CONTACTING SURFACES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to metallic mechanical systems comprising two opposing surfaces maintained in frictional contact with each other.

2. Description of the Prior Art

Aluminum and many of its alloys have poor sliding or frictional behavior against themselves and other metals. This may be attributed to the fact that aluminum has a high surface energy and strong alloying tendencies which allow it to bond readily with other metals. Moreover, since it is soft and ductile and its crystal contains a large number of slip systems, large contact areas can be produced, thus increasing the tendency to weld and to surface flow. Although aluminum surfaces often are covered with an oxide coating, and oxide coatings are known to be a significant factor in preventing surface damage by friction or sliding, the oxide film of aluminum is hard and brittle and, being on a soft substrate, is easily fractured. As soon as the adherent protective oxide film is broken, cold welding and sintering of the exposed sliding metal can occur. Even under lubricating conditions, sliding, contacting metallic surfaces are characterized by frequent metal-to-metal contact across the lubricant film. Aluminum and its alloys are particularly susceptible to galling or surface damage, usually with metal transfer, under such circumstances.

Because of its poor frictional behaviour, aluminum has not been used extensively in machines and load-bearing systems where one or more aluminum parts are in sliding contact with other parts, even under conditions of boundary lubrication. Such use of aluminum would be desirable because of its light weight and relatively low cost. In many applications where aluminum is used, protective coatings or liners are employed, the coating or liner being a metal not subject to the aforesaid defects. For example, in a rotary pump of the sliding vane or 2-or 3-lobe type, a liner or coating is used inside the shell to prevent galling of the aluminum, rapid wear of aluminum which destroys effective sealing contacts, and binding of the rotating parts by metal transfer.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a mechanical system having opposing contacting surfaces, one of which is aluminum, and means for frictionally moving the surfaces. Another object is to provide such a system wherein a fluid film is present between the surfaces. Still another object is to provide such a system wherein the movement of the surfaces can be carried out under boundary lubricating conditions. A further object is to provide an aluminum based mechanical system having opposing surfaces capable of frictional movement, which system does not require a liner or coating on the aluminum based surface. In summary, these and other objects are fulfilled by means of an improvement in a system capable of mechanical operation and comprising a first part presenting an aluminum surface, a second part presenting a second surface designed to be in repeating sliding contact with the aluminum surface, and means to induce and maintain the aluminum surface and the second surface in sliding relation to each other during the operation of the system, the improvement consisting of providing a second surface which is a metallic surface consisting of an alloy containing at least 60 atom percent of at least two heavy metal transition elements, the ratio of the atomic radii of the largest to the smallest of the heavy metal transition elements being in the range 1.05–1.68, and consisting of 10–100 volume percent of a hard phase and 0–90 volume percent of a matrix phase which is softer than the hard phase, said hard phase containing a major fraction of Laves phase in such amount as to provide at least 10 volume percent thereof in the alloy.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a test apparatus such as that employed in the examples to evaluate alloys. As a test apparatus it represents an embodiment of the mechanical system of this invention when it comprises a first part presenting an aluminum surface, a second part presenting a surface of alloy as defined herein, which surface is capable of being maintained in sliding contact with the aluminum surface of the first part, and means for inducing and maintaining the two surfaces in sliding contact with each other. FIG. 2 depicts a cross-sectional view through the rotor axis of a pump with a rotatable sliding vane assembly embodying peripheral sliding contact between sliding vanes and the pump shell. FIG. 3 depicts a cross-sectional view through the rotor axes of a pump with a two-lobe cooperating contrarotating assembly embodying sliding contact between the lobes and the pump shell. FIG. 4 depicts a cross-sectional view through the rotor axes of a pump with a three-lobe cooperating contrarotating assembly embodying sliding contact between the lobes and the pump shell. FIG. 5 depicts a sectional view along a common axis of a cylinder and an enclosed piston embodying a sliding contact between them. FIG. 6 depicts a sectional view along a common axis of a cylinder and an enclosed piston ring embodying a sliding contact between them.

DETAILED DESCRIPTION OF THE INVENTION

It has been found that when a surface of an aluminum based metal is in sliding contact with a surface comprising an alloy as defined herein, the aluminum based metal suffers little wear and surface damage. In many cases, the coefficient of friction of the aluminum based metal is surprisingly low, often as low as conventional bearing metals, against such alloys. This invention is applicable to a wide variety of mechanical systems characterized by two or more parts in repeating sliding contact with each other during system operation, especially when boundary lubrication conditions exist at the contact. Boundary lubrication can exist when sliding speeds are so low and contact pressures so high that the existence of load-supporting hydrodynamic wedges of lubricant are physically impossible. Sliding contact can exist when a load-bearing roller is rolled over a supporting surface.

In the description which follows, the aluminum based surface and the alloy based surface in moving or operational contact with each other are referred to as sliding couples. According to the invention, each sliding couple comprises aluminum, that is, aluminum or an alloy thereof, as one surface and an alloy, as defined herein-after, as the other surface. Either part can be movable or fixed in place provided that at least one in each couple is movable, that is, able to move in sliding contact with the other. Maintenance of movement between the surfaces can be by a variety of means. Included are such means that can provide timed intermittent sliding contact between surfaces of two moving cooperating parts, that can provide oscillatory or reciprocatory sliding contact between two parts, only one of which may be moving, and that can provide sliding contact between one surface in a repeated circular sliding motion along the other surface.

In accordance with this invention, the alloy based surface in the mechanical system can be provided in any known, convenient suitable manner. For example, it can be the surface of a part which is made entirely from the alloy. It can be a separate preformed alloy layer mechanically attached to an underlying surface or bonded thereto according to known techniques. It can be obtained by thermal diffusion of the alloy onto the base part by known techniques, for example, as disclosed in U.S. Pat. No. 3,331,700. Other known processes for obtaining the alloy based surface include weld overlaying, plasma arc spraying, powder metallurgy and casting. Surfaces of Laves phase-containing alloys should be sufficiently deep to allow for the wear acceptable to the mechanical system in which it is used. As a coating, this thickness usually is 0.001–0.40 inch, according to the size of the mechanical system in use, preferably, 0.002–0.03 inch. Overlays anchored by welding or mechanical attachment usually are at least 0.125 inch.

It is essential that the alloy composition of the surface which is in sliding contact with aluminum based metal comprise a hard phase containing a major amount of a Laves phase as disclosed above. In most alloys comprising a hard phase and a soft phase the hard phase is substantially all Laves phase. In some alloys the hard phase contains a major fraction, that is, greater than 50 volume percent, of Laves phase and a minor fraction, that is, less than 50 volume percent, of another hard phase which accompanies the Laves phase, often surrounding it. For example, in certain alloys consisting essentially of Co, Mo, Si and Cr, especially when the Cr content is at least 12 weight percent, the Laves phase is surrounded by another hard phase. The surround is present as a minor fraction, usually less than 25 volume percent, of the hard phase. A Laves phase contains one or more metallographic constituents that have the C_{14} (hexagonal), C_{15} (cubic) or C_{36} (hexagonal) crystal structure as described in "International Tables for X-Ray Crystallography," Symmetry Groups N. F. M. Henry and K. Lonsdale, International Union of Crystallography, Kynoch Press, Birmingham, England (1952). Prototypes of the Laves phase crystal structures are, respectively, $MgZn_2$, $MgCu_2$ and $MgNi_2$. Such phase structures are unique crystal structures that permit the most complete occupation of space by assemblages of two sizes of spheres. Fundamentally, the Laves phase can be represented by the formula AB_2, the large atoms A occupying certain sets of crystallographic sites and the small atoms B occupying other sites, in which the ratio of atomic radii A:B is in the range 1.05–1.68. Laves phases occur as intermediate phases in numerous alloy systems. Laves phases generally have a homogeneity range, that is, they can have any of a range of elemental compositions while maintaining their characteristic crystal structure. The atom ratio B:A can form slightly less to slightly more than **2**, possibly the result of some vacant sites in the crystal structure. Also, more than one kind of atom can occupy the large atom sites, the small atom sites, or both. Such Laves phases can be represented stoichiometrically by the formula $(A_{1-x}C_x)(B_{1-y}D_y)$ 2 where C represents the atoms of one or more kinds that substitute for the large atoms, D represents the atoms of one or more kinds that substitute for the small atoms, of the binary Laves formula AB_2, and x and y have values in the range 0–1.

An alloy, as the term is used herein, is a substance having metallic properties and containing in its elemental composition two or more chemical elements of which at least two are metals; other elements can be present. A heavy metal transition element is a metal selected from the group consisting of Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, Pt, Mn, Re, Cr, Mo, W, U, V, Nb, Ta, Ti, Zr, Hf, Th, Sc, Y, La, Zr and Ce.

Numerous binary and higher Laves phases which are suitable for purposes of the invention and containing at least two heavy transition metals are disclosed in the prior art. For example, binary and ternary Laves phases are shown in "Alloy Chemistry of Transition Elements," M. V. Nevitt, pages 101–178, especially Tables XIII and XIV, appearing in "Electronic Structure and Alloy Chemistry of the Transition Elements," P. A. Beck, Interscience - Wiley, New York, N.Y., 1963. Typical alloys consisting largely or entirely of ternary and higher Laves phase are disclosed in Table I.

TABLE I

Alloys	
$Ti_{30}Mn_{56}Si_{14}$	Mo_2Ni_3Si
TiFeSi	MoCoSi
Ti_2Ni_3Si	Mo_2Co_3Si
$V_4Co_5Si_3$	$Mo_{25}Mn_{47.5}Si_{27.5}$
$V_4Ni_5Si_3$	W_2Mn_3Si
$Nb_3Cr_5Si_2$	WFeSi
	$W_{40}Fe_{50}Si_{10}$
Nb_2Ni_3Si	WCoSi
$Ta(Cr,Co)_2$	W_2Co_3Si
$Ta(Cr,Cu)_2$	WNiSi
Ta_2Ni_3Si	W_2Ni_3Si
$Ta(V,Mn)_2$	$Mn_3Co_3Si_2$
MoFeSi	$Mn_3Ni_3Si_2$
Mo_2Fe_3Si	$Zr(V,Fe)_2$
MoNiSi	$Zr(V,Co)_2$

Generally, in the hard phase-containing alloys useful in this invention the transition metal elements are selected from the group consisting of V, Hf, W, Ta, Nb, Mo, Ni. Co, Fe, Mn, Cr, Zr and Ti. Preferably, the hard phase-containing alloy consists essentially of a substantial amount of at least one metal A, a substantial amount of at least one metal B and Si, metal A being selected from Mo and W and metal B being selected from Fe, Cr, Co and Ni, the sum of the amounts of metals A and B being at least 60 atom percent of the alloy, the amount of Si and the relative amounts of metals A and B being such as to ensure that 10–100 volume percent of the alloy is hard phase, the hard phase being distributed in a relatively soft matrix of the remaining 0–90 volume percent of the alloy. More preferably, 20–85 volume percent of the hard phase (containing at least 75 volume percent, and preferably, substantially all, Laves phase) is distributed in 15–80 volume percent of matrix phase. The matrix can be formed of the same alloy system as the hard phase; it can be a single metal, a solid solution, one or more intermetallic compounds other than Laves phase or a mixture of solid solution and said intermetallic compounds. It must be softer than the hard phase and, generally, should have no more than about 50 percent of the Knoop hardness of the hard phase. Preferred metal matrix phases exhibit a Knoop hardness of 350–750.

Cobalt based alloys useful herein and having the requisite amount of hard (including Laves) phase include those disclosed in U.S. Pat. Nos. 3,180,012 and 3,410,732. Alloys containing silicon and at least two heavy transition elements selected from the group consisting of Mo, Co, W, Ni and Cr include those disclosed in U.S. Pat. No. 3,361,560.

Other hard, substantially 100 percent Laves phase-containing alloys useful herein include those disclosed in Tables II and III (the latter preferred) wherein the elements are expressed in weight percent and the hard phases are expressed in volume percent.

TABLE II

Co	Ni	Mo	Si	Fe	Mn	Other	Hard Phase
		52	18	30			70
		36		46		18 Ge	50
	10	36	18	36			60
			15		58	27 Ta	35
	45		15			40 Nb	28
38			10			52 Ta	35
60			10			30 Ti	25
45		48	7				about 100
32		52	16				about 100

versus temperature) of at least 250°C. and a room temperature modulus of at least 300,000 p.s.i., for example, phenol-formaldehyde resins, aromatic polyimides, aromatic polyamides, aromatic polyketones, aromatic polythiazoles and polybenzotriazoles. Binders can comprise up to 90 percent of the binder/alloy mixture.

The aluminum based surface which is in contact with the previously described Laves phase-containing surface generally contains at least 84 percent aluminum. It can be aluminum alone, for example, greater than 99 percent aluminum or it can be an alloy of aluminum and another element or elements; alloying elements include Mg, Mn, Zn, Cu, Ni, Cr, Ti and Si. Preferably, its aluminum content is at least 92 percent. Useful aluminum alloys include those designated as follows by the American Society for Metals, with the compositions being given in parentheses (if not shown, Al is the balance to 100 percent): alloy 1000 (greater than 99.6% Al); 2024 (4.5% Cu, 1.5% Mg, 0.6% Mn); 2218 (4% Cu, 2% Ni, 1.5% Mg); 4032 (12.5% Si, 1% Mg, 0.9% Cu, 0.9% Ni); 5154 (3.5% Mg, 0.25% Cr); 6061 (1% Mg, 0.6% Si, 0.25% Cu, 0.25% Cr); A13 (12% Si); A132 (12% Si, 2.5% Ni, 1.2% Mg, 0.8% Cu); and 40E (5.5% Zn, 0.6% Mg, 0.5% Cr, 0.2% Ti). Preferred alloys include 1000, 2024, 2218 and 40E as well as 5456 (5% Mg, 0.7% Mn, 0.15% Cu, 0.15% Cr); 142 (4% Cu, 2% Ni, 1.5% Mg); and 195 (4.5% Cu). Alloy 2024 is especially preferred.

TABLE III

Co	Ni	Mo	W	Si	Cr	C	Hard Phase	Knoop Hardness Hard Phase	Knoop Hardness Matrix
59.7		27.9		4.0	7.9	0.5	60	1481	569
57.6		27.8		2.0	12.0	(1)	40	920	450
62.0		28.0		2.0	8.0	(2)	40	1481	735
70		28		2			20	1039	(3)
65		25		10			50	1039	(3)
65		29		6			50	1039	(3)
65		33		2			50	1039	(3)
60		30		10			58	1220	(3)
60		34		6			65	950	(3)
60		38		2			50	1039	(3)
55		35		10			65	1231	(3)
55		39		6			78	1200	(3)
55		41		4			85	954	(3)
55		43		2			75	900	(3)
50		48		2			76	1443	(3)
	55	35		10			65	824	316
	53	35		3	9		55	1170	370
	40		51	9			45	—	—
40			45	15			35	—	—
50		44		6			75	—	—
	58	35		7			80	—	—

(1) 0.6 Mn instead of carbon
(2) 0.01 B and 0.2 Zr instead of carbon
(3) Less than that of the Hard phase; generally, 350–750

The alloy based surface can be 100 percent of the defined alloy or a mixture of the alloy and a binder which binds the alloy in place without destroying its Laves phase. Binders should be inert to, that is, nonreactive with, and softer than the Laves phase of the alloys they bind. They should also be inert to the aluminum based surface of the sliding couple. Binders can be selected from metals and resins. Metals can be selected from the heavy metal transition elements, Cu, Ag and Au, as well as from alloys of these metals. Typical binder metals include nickel, cobalt, iron, bronze and selected iron alloys. Resins include phenolic resins and essentially linear resins having a second order transition temperature (as determined by plots of flexural modulus

Anodized aluminum is also operable in this invention as the aluminum based surface. The depth of the anodized layer is easily determined by test and typically is in the range 90–2,000 microinches; generally, it is in the range 300–1,200 microinches.

The mechanical systems of this invention containing two opposing surfaces can be used in many instances in the absence of a lubricating agent; in other words, they are self-lubricating. Examples of such an application include an air control valve which must have no contact of air with lubricant and a Corliss or slide valve for steam engine operation.

The mechanical systems of this invention also are operable in the presence of non-lubricating fluids, such as water, wet steam or other fluid media, to which the sliding couple may be exposed, for example, rotary pumps for pumping hot water or a hydraulic fluid and a system employing the sliding contact of a poppet valve stem along an enlosing guide.

When a mechanical system of this invention is operated with a lubricating fluid under boundary lubrication conditions, it provides a service life well beyond what is customarily obtained in the art.

The sliding couple, that is, the mechanical system of this invention in operation, can be in the form of an elongated contact across the direction of slide, the contact separating two bodies of fluid. Such a contact exists between a cylinder and an enclosed piston or piston ring designed to slide on a common axis. It can also be found in rotary pumps of the vaned, 2-lobe and 3-lobe types between the interiors of the curved shells and the sealing wipers on the rotating parts. Such pumps include rotatable sliding vane assemblies, 2-lobe contrarotating assemblies and 3-lobe contrarotating assemblies. The sliding couples obtainable by this invention can be used in air- or liquid-driven rotary devices for converting fluid energy to mechanical power. The present invention provides an alternative to the use of slide surfaces in such mechanical systems which heretofore comprised non-galling materials or shells of aluminum protected by liners of non-galling materials. Sliding couples obtainable by means of this invention retain their ability to maintain the separation of fluid bodies without galling or rapid wearing of the aluminum. The present invention makes possible the simplification of pump designs, expansion of choice in the selection of useful materials, especially lighter materials, and reduced construction costs.

DETAILED DESCRIPTION OF THE DRAWINGS

In the test apparatus represented by FIG. 1 holder 1 is anchored to a fixed reference (not shown) and holds test plate 2 level and in place by means not shown. Holder 1 contains electrical cartridge heaters, below test plate 2, which maintain elevated plate temperatures where desired. Holder 1 has containing capacity, above test plate 2, in which lubricating or other liquids can be maintained during tests. Pin 3 is circular bar stock of the material used in sliding test against the surface of plate 2 while the pin end surface is horizontal. Pin 3 is held vertically positioned by clamp 4 and clamp tightening means (not shown). Clamp 4 is integral with one end of reciprocating bar 5. Bar 5 has yoke 6 at its other end and is guided in horizontal linear motion by bushings 7 and 8, both anchored to said fixed reference. Yoke 6 is linked to oscillating means of controlled frequency and stroke. Load bearer 9 is level on top of clamp 4, is positioned perpendicular to the movement direction of bar 5 and has the axis of its pivot hole 10 normal to the plane of plate 2. It is long enough that it swings less than 10 degrees over the oscillating range of bar 5 and its fit at the top of clamp 4 corresponds to a single plane. Weights (not shown) are loaded on top of load bearer 9, centered by the pin 3 axis to the extent needed to produce the desired pressure on the bottom end of pin 3. The manner of using this apparatus is described in the examples.

FIG. 2 depicts a pump with a line contact across the direction of sliding between the pump shell and the surface of sealing wipers in a rotatable sliding vane assembly. Pump shell 15 is provided with cylindrical chamber 16 in communicating relation with inlet 17 and outlet 18. Cylindrical rotor 19, having vane slots 20, 21, 22 and 23, is provided with radial vanes 24, 25, 26 and 27 biased radially outward (by means not shown) against the periphery of chamber 16. The center of rotor 19 is displaced so that space between it and chamber 16 is carrier space for fluid entering inlet 17 to be carried by adjacent vanes to outlet 18. Shell 15 and rotor 19 are of an aluminum based metal. Vanes 24, 25, 26 and 27 are of a Laves phase-containing alloy as described herein and they freely slide radially toward and away from the rotor during its rotation to keep them in continuous sliding contact with the periphery of chamber 16 during pump operation.

FIG. 3 depicts a pump with a line contact across the direction of sliding contact between the pump shell and the lobes of a two-lobe cooperating contrarotating assembly. Rotors 31 and 32 are viewed through their parallel axes. They rotate in opposite directions in cooperation with gears (not shown), one on each rotor shaft, intermeshed with each other. The rotors rotate in overlapping cylindrical chambers which communicate with inlet 33 and outlet 34 inside shell 35 which is of an aluminum based metal. Rotors 31 and 32 are coated on their exterior surfaces 36 and 37 with a Laves phase-containing alloy as described herein and they are in sliding contact with each other and with shell 35 at its internal periphery and at its cylindrical ends.

FIG. 4 depicts a pump with a line contact across the direction of sliding contact between the pump shell and the lobes of a three-lobe cooperating contrarotating assembly. Rotors 41 and 42 are viewed through their parallel axes. They rotate in opposite directions in cooperation with gears (not shown), one on each rotor shaft, intermeshed with each other, inside aluminum based metal shell 43. Shell 43 is internally shaped to provide overlapping cylindrical chambers 44 and 45 communicating with inlet 46 and outlet 47. Rotors 41 and 42 are in close sliding contact with each other and with the internal surface of shell 43. They are coated on their exterior surfaces 48 and 49 with a Laves phase-containing alloy as described herein.

FIG. 5 depicts a sectional view along the axis of a cylinder and an enclosed piston designed to slide on a common axis. Piston 51 fits sealably inside cylinder 52 and is axially movable therein. Piston 51 has coating 53 of a Laves phase-containing alloy as described herein around its periphery. Coating 53 provides an elongated contact across the direction of piston slide which separates fluid body 54 from fluid body 55.

FIG. 6 depicts a sectional view along the axis of a cylinder and an enclosed piston ring. Piston 63 fits inside cylinder 56 in a loosely sealable fit and is axially movable therein. Piston 63 has annular grooves which support piston rings 57, 58 and 59 sealably inside cylinder 56. The peripheries of rings 57, 58 and 59 have coatings 60, 61 and 62 of a Laves phase-containing alloy as described herein. These coatings provide an elongated contact across the direction of slide which separates fluid body 64 from fluid body 65.

In the following examples percentages are by weight unless otherwise noted.

Example 1 - Performance With Lubricating Oil

This example tests sliding contact under boundary lubrication conditions between the contacting surfaces. 0.375 Inch diameter pins having polished flat ends were machined from solid rod of the following materials:

A. Alloy 2024-T4 (Alloy 2024 solution heat treated according to test procedure of "Metals Handbook," Vol. 1, Properties and Selection of Metals, T. Lyman, American Society For Metals, page 888–9).

B. Alloy 2024-T4, with the pin being anodized on its flat end to a depth of 1,000 microinches.

C. Lead Tin Bronze SAE 660, a common bearing material having the composition 83 percent copper, 7 percent tin, 7 percent lead and 3 percent zinc.

D. Tin Bronze SAE 62, a common bearing material having the composition 88 percent copper, 10 percent tin and 2 percent zinc.

1 Inch by 2 inch coupons of 410 Stainless Steel were plasma sprayed with 0.015 inch coatings of one of the metals described below. The sprayed coatings were sintered and then ground to a thickness of 0.004–0.008 inch. The metals were:

E. An alloy of 55% cobalt, 35% molybdenum and 10% silicon, of which 65% by volume was Laves phase and 35% by volume was matrix phase.

F. A mixture of 80 percent of the alloy of E and 20 percent nickel. The nickel acted as a binder for the alloy after sintering.

The pins were weighed and the coated surface profiles of the coupons were measured using a profilometer. Each pin was mounted in an oscillatory mechanism so that it could be drawn back and forth at sinusoidally variable speed in 0.5 inch strokes while its flat end was in constant and complete contact with a flat sintered coating of a coupon. The contact area was submerged in a 10W-40 base hydrocarbon oil. Each pin was loaded to 1000 p.s.i. pressure against the plate and oscillated at 5 feet per minute average velocity. Friction was measured during the oscillation. The system was operated at room temperature until the friction was constant, about 15 minutes. Thereafter, the system was heated to 38°C., run for 5 minutes at that temperature, and its friction was again measured. At 28°C. intervals, this procedure was repeated until 204°C. was reached. At 204°C. the test was continued for 30 minutes. The system was then cooled and the coated coupon and pin specimens were removed and heated to 232°C. for 24 hours to drive off oil. Each pin was weighed to determine its weight change and the surface profile along the friction path of each corresponding coated coupon was again measured with a profilometer to determine the amount of surface damage produced.

The pins also were tested against the surfaces of flat 0.25 inch by 1 × 2 inch blocks of metals having the following compositions:

G. M2Tool Steel, having the composition 0.85 percent carbon, 4 percent chromium, 2 percent vanadium, 6.25 percent tungsten, 5 percent molybdenum and the balance iron. This is a commonly used wear resistant pump shaft material.

H. 416 Stainless Steel, a martensitic free machining steel often used for machine parts and pump shafts, having the composition 12–14 percent chromium, 0.15 percent maximum carbon, 0.06 percent maximum phosphorus, 1 percent maximum sulfur and the balance to 100 percent iron.

Table IV shows the test data obtained. In the table the coefficient of friction is the ratio of the applied drag (or force tangent to the load) to the pin load (or force normal to the load). The CLA value is the center line average of variations in surface height along a line of measurement across the direction of sliding contact on the coupon or block as measured by the profilometer. It is expressed as the arithmetic average, in microinches, of deviations from a plane. Visual ratings were based on observations of 6.6X photographs of tracks rubbed by the pins and of direct 10X viewing of the tracks using the scale:

1 No visible score marks
2 A few visible score marks
3 Signs of seizure or transverse microcracks.

TABLE IV

Pin	Flat Face	Coefficient of Friction Highest	Lowest	After Test	Pin Wt. Change (Gram)	CLA Before Test	After Test	Visual Rating
A	E	0.25	0.19	0.23	−.0037	7.0	80.0	2
B	E	0.15	0.11	0.11	+.0036	9.5	10.0	1
C	E	0.28	0.18	0.22	−.0011	10.0	9.5	1
D	E	0.21	0.13	0.18	−.0009	10.0	14.5	2
A	F	0.27	0.14	0.18	−.0034	8.0	14	2
B	F	0.21	0.13	0.18	+.0031	11.0	21.0	1
C	F	0.29	0.23	0.23	−.0067	9.0	14.5	1
D	F	0.28	0.19	0.19	−.0006	9.0	9	2
A	G	0.37	0.28	0.29	—	2.5	7.0	3
A	H	0.25	0.21	0.21	−.0014	11.5	40.0	3

It can be seen that under boundary lubrication conditions, an aluminum surface rubbing against a Laves phase-containing alloy surface is comparable to and sometimes superior to generally used bronze bearing materials rubbing on Laves phase-containing alloys. Furthermore, it can be seen that an aluminum surface rubbing against a Laves phase-containing alloy is superior to an aluminum surface rubbing against commonly used construction steel. The results also show that metal transfer to the Laves phase-containing alloy by an aluminum alloy or anodized aluminum alloy is comparable to that of generally used bronze bearing materials and less than that of a frequently used steel.

Example 2 - Performance with Water and Wet Steam

This example tests sliding contact with a nonlubricating fluid between the contacting surfaces. Pins were prepared as in Example 1 from materials A–D. As in Example 1, coupons were prepared and coated with metal F. The pins also were tested against the surfaces of flat 0.25 inch by 1 by 2 inch blocks of metal cast from

I. An alloy of 62 percent cobalt, 28 percent molybdenum, 8 percent chromium and 2 percent silicon, of which 50 percent by volume is Laves phase and 50 percent by volume is matrix phase.

Each pin was mounted in the mechanism of Example 1 with its flat end in constant and complete contact with the sintered coating of a coupon or the flat face of a block. The contact area was submerged in water. At 1000 p.s.i. pin end loading and at 5 feet per minute average velocity, the system was operated at room temperature until constant friction was achieved, about 15 minutes. Thereafter, the system was heated to 38°C., run for 5 minutes at that temperature and its friction was measured. At 14°C. intervals, this procedure was repeated until 93°C. was reached. At 100°C. the test was continued 30 minutes, with friction measurement at 5 minute intervals as the water boiled. The system was then cooled and the block and pin specimens were removed and heated to 149°C. to drive off water. The pin and block or coated coupon of each combination were weighed to determine their weight changes. The flat face profiles of the blocks and coated coupons were measured across the rubbing paths of the pins to determine changes in those surfaces. The visual ratings of the rubbed parts of the flat faces were also determined employing the scale used in Example 1. Table V shows the test data obtained.

TABLE V

Pin	Flat Face	Coefficient of Friction			Wt. Change (Gram)		CLA		Visual Rating
		Highest	Lowest	After Test	Pin	Block	Before Test	After Test	
A	F	0.44	0.21	0.38	−.0017	−.0020	9.2	7.5	—
B	F	0.52	0.18	0.44	+.0002	+.0080	8.0	6.0	1
C	F	0.18	0.11	0.18	−.0014	+.0012	10.0	8.0	1
D	F	0.23	0.11	0.23	−.0016	−.0010	10.0	11.0	1
A	H	0.62	0.43	0.59	−.0030	—	10.0	20.0	3
A	I	0.64	0.50	0.50	−.0033	−.0010	4.0	2.5	1
B	I	0.85	0.49	0.81	+.0015	+.0003	7.5	3.5	2
C	I	0.37	0.15	0.36	−.0004	+.0003	7.0	4.5	1
D	I	0.32	0.16	0.32	−.0006	+.0003	7.0	9.0	3

The results show that under the poor lubricating conditions provided by water the surface damage to Laves phasecontaining alloy surfaces produced by aluminum alloy or anodized aluminum alloy is comparable to or less than that produced by generally used bronze bearing materials and commonly used construction steel.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An improved mechanical system comprising a first part presenting an aluminum surface, a second part presenting a second surface in contact with the aluminum surface, and means for inducing and maintaining the two surfaces in sliding contact with each other, the improvement consisting of employing as the first surface an aluminum based surface and as the second surface a metallic surface comprising an alloy containing at least 60 atom percent of at least two heavy metal transition elements, the ratio of the atomic radii of the largest to the smallest transition elements being 1.05 –1.68, and consisting of 10–100 volume percent of a hard phase and 0–90 volume percent of a matrix phase which is softer than the hard phase, said hard phase containing a major fraction of Laves phase in such amount as to provide at least 10 volume percent thereof in the alloy.

2. The system of claim 1 wherein the aluminum surface is anodized.

3. The system of claim 1 wherein the second surface is a mixture of alloy and a binder which is inert to and softer than the Laves phase of the alloy.

4. The system of claim 1 wherein the alloy based surface has a thickness of 0.001–0.40 inch.

5. The system of claim 1 wherein the two surfaces are in operational sliding contact with each other.

6. The system of claim 5 wherein the sliding contact is an elongated contact across the direction of the slide and the sliding contact separates two bodies of fluid.

7. The system of claim 1 wherein the transition elements are selected from the group consisting of V, Hf, W, Ta, Nb, Mo, Ni, Co, Fe, Mn, Cr, Zr and Ti.

8. The system of claim 7 wherein the hard phase-containing alloy consists essentially of a substantial amount of at least one metal A, a substantial amount of at least one metal B, and Si, metal A being selected from Mo and W, metal B being selected from Fe, Cr, Co and Ni, the sum of the amounts of A and B being at least 60 atom percent of the alloy.

9. The system of claim 8 wherein the amount of Si and the relative amounts of A and B are such that 20–85 volume percent of hard phase is distributed in 15–80 volume percent of matrix phase.

10. The system of claim 9 wherein the hard phase is substantially all Laves phase.

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