May 13, 1941. P. E. QUENEAU ET AL 2,241,789

BEARINGS AND METHOD OF PRODUCING THE SAME

Filed May 27, 1938

Fig. 1.

Fig. 2.

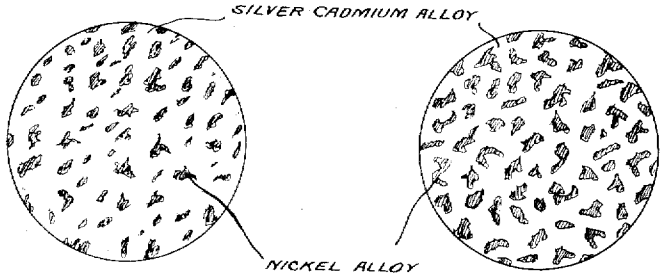


Fig. 3.

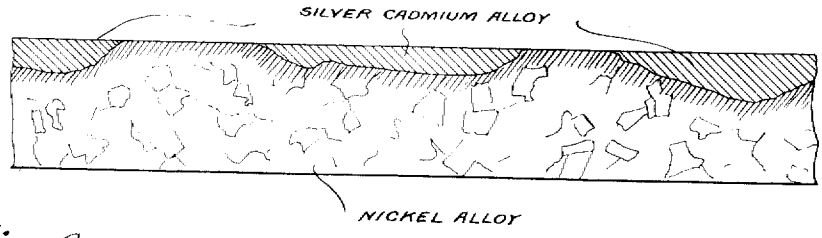
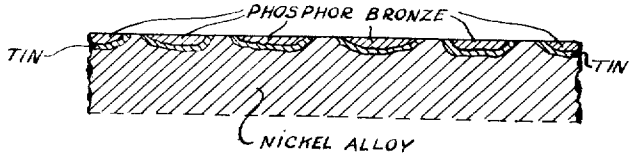


Fig. 4.



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BEARINGS AND METHOD OF PRODUCING THE SAME

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The present invention relates to bearings and to a method of producing anti-galling metals and alloys, and, more particularly, to non-corrosive, high strength, anti-galling metals and alloys.

It is well known that there have been many bearing (anti-friction) alloys containing principally lead, tin, antimony, copper, etc., but these have only a moderate resistance to certain types of corrosion and were generally soft. Usually these alloys possessed low melting points and low resistance to high temperature. Other bearing metals, such as bronze, lead-copper, or hard lead type have fulfilled some of the requirements of hardness and strength, but do not satisfy the most exacting corrosion-resisting requirements, particularly of sea water corrosion. Furthermore, good and adequate lubrication is necessary at all times. Case hardened steels have relatively good anti-galling properties and very high strength and hardness, but have little or no resistance to corrosion. A malleable, high strength metal or alloy having good resistance to corrosion in most media and good anti-galling or anti-friction properties when used for rolling and/or sliding friction has not been commercially available. The art has been confronted with a problem requiring the production or treatment of alloys having relatively high tensile strength, such as about 100 or 140 to 160,000 pounds per square inch tensile strength with a minimum of 20 per cent elongation, having excellent corrosion resistance to salt water and certain other agents operating without galling under sliding and rolling friction, and being self-lubricating. In connection with the use of alloys of the aluminum-copper-nickel series described in the U. S. Patent No. 1,572,744 to Merica and the U. S. Patents Nos. 1,755,554, 1,755,555, 1,755,556 and 1,755,557 to Mudge under conditions where anti-galling is required, it has been customary in the past to treat the surface by "wiping" a very thin layer of tin or solder thereon. This was satisfactory in service only as long as the tin remained intact. However, since the tin or the anti-friction ("layer") metal was only in mechanical contact with the underlying ("base") metal, the former soon wore off and failed to provide the necessary protection against galling. Moreover, the bearing surface possessed poor resistance to sea water corrosion.

Although many attempts have been made to solve the outstanding and vexatious problem confronting the art, none, as far as is known, has been wholly successful and satisfactory when carried into practice on an industrial scale for the production of commercial products.

We have discovered that the aforesaid problem may be solved in a remarkably simple manner and that the art may be provided with an improved anti-friction and anti-galling structure having high strength and corrosion resistance.

It is an object of the invention to provide a process of producing an improved anti-galling and anti-friction structure constituted of a metal or alloy so treated as to fulfill the multiple requirements of high strength and hardness, good resistance to corrosion and to relatively high temperatures, and ability to operate under conditions of sliding and/or rolling friction without failure through galling or seizing.

It is another object of the invention to provide a method of producing improved anti-galling and anti-friction bearings, particularly those resistant to corrosion and high temperatures, on an industrial scale in a practical manner.

It is a further object of the invention to provide composite metallic anti-friction and anti-galling bearings in which the bearing surface is made up of a plurality of small islands of an under layer of metal surrounded by a matrix of bearing metal.

Other objects and advantages will become apparent from the following description taken in conjunction with accompanying drawing, in which:

Figs. 1 and 2 are views representing photomicrographs of the present improved anti-friction and anti-galling structure illustrating desirable types of bearing surfaces;

Fig. 3 represents a photomicrograph of a cross section of an improved anti-friction and anti-galling structure showing "mountains" or projections on the roughened face of the underlying base or foundation stratum peeping through the applied layer of anti-friction metal; and

Fig. 4 is similar to Fig. 3 and illustrates schematically a cross section of an embodiment of the invention employing a plurality of layers of metal, the first or intermediate layer acting as a bonding layer.

Broadly stated, the invention contemplates the process of applying an anti-friction metal or alloy to the face of a base metal to form a composite material. This composite material is then preferably heat treated to cause or tend to cause the layer metal and the base metal to diffuse into each other. As a result a novel and efficient bond is formed between the "layer" and the "base" materials and combines the hardness and resistance to corrosion of the base metal with the anti-galling properties of the layer metal. Furthermore, the bonding provides a means of keeping this layer intact with the base so that it will not strip or wear off in service as usually occurred heretofore in the cases of the conventional wiped tin layer.

Our invention, generally speaking, comprises

applying a thin layer of relatively soft, special anti-friction metal or alloy to the face of a hard, high strength corrosion-resisting metal or alloy, thus forming a composite product without, however, the layer metal or alloy being, at this step in the process, integral with the base metal or alloy. This composite material is then preferably heat treated so as to cause or tend to cause diffusion of the two metals or alloys ("layer" and "base") into each other, with the resulting formation of an intermediate bond between the two so that the final product is a single, unitary structure of integral character possessing unusual and critical properties.

In carrying the present invention into practice, it is to be observed that the nature of the bond between the base and layer metals or alloys will vary with the chemical and physical properties of these materials. Some will bond more readily than others, some produce a greater thickness in the bonding than others, and in some cases the amount of bonding is very small. Nevertheless, the superior performance of and new results produced by the novel heat-treated products is direct evidence that the heat treatment is beneficial and desirable. It is also true that the heat-treatment produces a certain amount of sintering and intra-diffusion in the layer metal, when applied by spraying, for example, and that this is of distinct advantage in reducing (but not completely eliminating) the porosity thereof. Similarly, the heat-treatment would eliminate or would tend to eliminate a considerable percentage of occluded gases such as exist in electroplated surfaces, and, even in sprayed surfaces would assist in eliminating or reducing brittleness. In the broadest sense, therefore, the heat-treatment serves the multiple purpose of bonding the layer material to the base material in varying degrees, of sintering the particles of the layer material together, and of eliminating undesirable occluded gases, thereby ameliorating the physical properties thereof. In corrosion-resisting services this latter feature is of great importance. When the heat-treatment is conducted in an atmosphere of reducing gases, it tends to eliminate oxides by reduction, particularly in the cases of sprayed coatings.

As those skilled in the art will readily understand, the selection of the exact nature or properties of the layer material must be governed by the type of service desired. For example, if the corrosive medium in which the alloy must work is a sulphuric acid medium, a lead-containing layer alloy would preferably be chosen; if the corrosive medium is sea water, a silver-cadmium layer alloy containing about 10 to 95% of silver with the balance cadmium would preferably be chosen. Particularly satisfactory results have been obtained within the range of about 65 to 95% silver, and a preferred range is about 75% to 85% silver, with the balance substantially cadmium. A similar choice may also be made with reference to the base metal. For example, if high tensile strength is desired combined with lightness (low specific gravity) one or more of the aluminum alloys of the age-hardening type would be selected; if high strength and hardness with corrosion resistance are desired, one of the alloys of the aluminum-copper-nickel type previously mentioned would preferably be chosen.

The present invention contemplates the use of a layer alloy which improves the corrosion resistance as well as the anti-galling properties of the base alloy, such as a silver-cadmium coating on steel. For special purposes, a generally considered base metal may also be used as a layer metal in order to impart specially desired properties together with bearing characteristics, such as, for example, the use of bronze on nickel alloys or the use of aluminum alloys on steel.

From a broad point of view, when resistance to corrosion is involved, the selection of the layer material is based in part upon the position of the materials involved in the well established electromotive series. For best results, not only the chemical properties of the layer material must be considered but also its position in the electromotive series. Its position in the series should, in general, be lower than that of the base material, i. e., the layer material should be cathodic with respect to the base material. A selection on the foregoing basis will serve to decrease the likelihood of corrosion of the layer material.

For the purpose of securing best results, especially in connection with sea water, we prefer to use a base constituted of nickel base alloys. Typical of such alloys are nickel-copper alloys sold under the trade-mark "Monel" and nickel-chromium-iron alloys sold under the trade-mark "Inconel." We may also use iron base alloys, such as the carbon and alloy steels, or copper base alloys, such as brasses, bronzes and nickel silvers, or aluminum base alloys, preferably of the age-hardening type, such as Duralumin.

For the layer, we prefer to use silver or cadmium or alloys thereof. We may likewise employ anti-friction materials, such as tin, zinc, aluminum, lead, copper, antimony, carbon (graphite), indium, berryllium, bismuth, gold, palladium, platinum, silicon, rhodium, etc., singly or in combination. Indium is of particular benefit in increasing the corrosion resistance of certain of the cadmium and copper base alloys.

The methods of applying the layer metal to the base metal depend upon the size, shape and general contour of the base metal. One or more of the following five methods, singly or in combination, may be used: (1) metal spraying; (2) electro-deposition (plating); (3) cementation; (4) dipping the base metal in molten layer metal; and (5) foil and layer method.

For purposes of description and illustration, we will consider a composite product produced by methods (1) and (5) as a mechanically composited product; and one produced by methods (2) (3) and (4) as a chemically composited product.

Spraying is generally to be preferred in cases where the base metal is large in size, irregularly shaped and otherwise difficult to handle by any of the other methods, and particularly when the layer metal chosen has a melting point so high that method (4) is not practical. Spraying also affords a practical method for controlling the porosity of the layer material. For optimum results, we believe that improved properties of the sprayed metal coatings may be had if the actual spraying is performed in a neutral atmosphere such as that provided by nitrogen. This, we believe, would tend to obviate surface oxidation of the individual sprayed particles and bring about the formation of a deposit having a denser structure more akin to that of a casting and improved physical and corrosion resisting properties. Such an atmosphere would also enable preheating of the base metal (for instance electrically) without resulting surface oxidation of

the latter. Such preheating would greatly enhance the satisfactory formation of a spontaneous diffusion bond at the base metal-layer metal interface. We believe that the bearing properties of a given sprayed metal bearing surface will be improved by the inclusion of minute graphite particles therein which tend to make the bearing "self-lubricating." This may be accomplished by the incorporation of graphite in the wire to be sprayed or by its injection into the spray zone proper. The method of electro-deposition (2) may be chosen where the base metal is generally regular in contour and easy to handle and for small complicated pieces. The advantages of electro-deposition include close control of exact compositions, thicknesses, and areas of deposit without danger of injuring the base metal. It is very advantageous where close tolerances are desired and where mass production is desired. The cementation method (3) which consists in heating, in a neutral or reducing atmosphere, the base metal in contact with the layer metal in powder form, may be chosen for very small base metal products such as nuts, bolts, etc., and also in cases where the applied layer metal or alloy is difficult to spray, as, for example, when the layer element is carbon, or silicon, or alloys which are brittle and cannot be drawn in to fine wire for the spraying operation. The dipping method (4) may be chosen when the layer metal has a low melting point. The foil method (5) will find special applications when the previously mentioned four methods are comparatively difficult to carry out.

Under certain conditions, it may be desirable to combine one or more of the above methods. For example, when it is difficult or impossible to obtain a diffusion bond between the layer and the base metals, an intermediate layer of a satisfactory bonding element or alloy will first be coated on the base metal prior to application of the selected layer material. In this manner, an anti-friction and anti-galling structure or bearing is produced comprising a base, an intermediate layer, and a bearing layer. Upon subsequent appropriate heat-treatment, the desired bond would be obtained, thus producing a structure or bearing comprising a plurality of irregular layers or laminations bonded to the base. For the purpose of providing specific corrosion-resisting properties to the base metal when the surface coating of bearing metal would be unsatisfactory for this purpose an intermediate metallic coat may be of value. While a diffusion bond is highly desirable, particularly if it has good physical properties, it is not absolutely necessary.

The thickness of the applied layer metal may vary within relatively wide limits, but for practical purposes thicknesses from about 0.0005 to about 0.050 inch have given satisfactory results. In any particular case, the thickness will be governed by the nature of the material used, its ease of application, its ease of bonding by heat-treatment, and the like. We have produced satisfactory coatings varying from 0.0005 to 0.050 inch and we prefer to keep the coating as thin as possible in order to combine the inherent properties of both base and layer metals. After heat-treatment, the surface of the work may be smooth machined or allowed to remain slightly rough as desired. Machining or grinding can be accomplished without undue difficulty since a properly bonded surface coating has fair to good ductility and density.

After the layer metal has been suitably applied by one or more of the above mentioned methods, the composite product is heated, preferably in a neutral or reducing atmosphere to prevent oxidation, in order to cause or tend to cause the formation of a good bond, preferably by diffusing one material into the other, or in other words, alloying them together so that the whole becomes integral and prevents the layer metal from being easily loosened in service. The temperature necessary to accomplish this bonding or this diffusion or alloying of the layer and base metal constituents, which will generally be called hereinafter "heat-treatment," varies with the physical and chemical nature of the metals and alloys used. Metals or alloys with low melting points require relatively low diffusion or heat-treating temperatures; metals or alloys with high melting point require obviously relatively high heat-treating temperatures. For example, if the layer metal is lead, tin, or indium, the bonding or the diffusion temperature will be within the range of about 300 to about 600° F.; if the layer metal is one of the silver-cadmium alloys the bonding or the diffusion temperature will be generally between about 700 and 900° F.; if, on the other hand, the layer metal is pure silver or gold the bonding or the diffusion temperature would be generally in the range of about 1000 to about 1600° F. In some cases, it may be stated that the bonding or the diffusion temperatures are selected so as to be in the general region below the melting point of the lowest melting metal in the system. This avoids melting of the lowest melting point metal during the heat-treatment with possible agglomeration, segregation, vaporization or oxidation which may change or tend to change the physical and chemical characteristics of the material. As those skilled in the art will readily understand, the selected temperature will depend on the thermal diagram of the alloy in question.

For the purpose of giving those skilled in the art a better understanding of the invention, we will now describe an illustrative method of manufacturing a high strength, non-corrosive base metal, such as one of the aluminum-copper-nickel alloys mentioned. These alloys have very poor anti-galling or anti-friction properties, so that they will be preferably surfaced with an integrally bonded 75–85 per cent silver and 15–25 per cent cadmium alloy. This surface coating has a thickness ranging from about 0.0005" to about 0.003" and has a good resistance to corrosion in sea water. The silver-cadmium alloy may be applied by spraying or by electrodepositing. After heat-treatment, the composite product will then possess the desirable strength, the corrosion resisting, and the anti-galling properties of the two materials.

An alloy steel might be substituted for the aluminum-copper-nickel base alloy and the same layer metal applied to it, or a lead-bearing solder may be substituted for the silver-cadmium alloy and applied to the aluminum-copper-nickel base metal.

The aluminum-copper-nickel alloy to be used was first hardened by the methods of heat-treatment which involve, generally speaking, heating and then cooling. A detailed description of the method is set forth in the U. S. Patent Nos. 1,755,554, 1,755,555, 1,755,556 and 1,755,557, to Mudge so that the proportional limit of the alloy is approximately 90,000 pounds per square inch,

its ultimate tensile strength approximately 150,000 pounds per square inch, its elongation in 2" approximately 20 per cent and its reduction in area approximately 30 per cent, its Rockwell C hardness approximately 30, and its Brinell hardness, using the 3000 kg. load, approximately 300.

In Table I are summarized the results obtained in a long series of tests on an aluminum-copper-nickel alloy or a copper-nickel alloy which was surfaced with different alloys and was treated in accordance with the principles of the present invention to produce a novel product. In these tests a ⅝" diameter rod was rotated in a 2 inch cubic block of the same metal, without lubrication of any kind and under considerable pressures:

Table I

Metal for 2 in. cubic block and for ⅝" diam. rod	Layer or coating on ⅝" diameter rod	Bonding or diffusion heat treatment (in hydrogen atmosphere)	Load	R. P. M.	Time to produce galling
A					
			Pounds		*Minutes*
Cu-Ni-alloy	None	None	600–650	24	0.75 to 1.2.
Do	do	do	1,000–2,000	24	1.25 to 6.08.
Do	Zinc	do	2,000	19	23.0 to 35.5.
Do	Chromium plated	do	2,000	19	3.0.
Do	Tin	do	2,000	19	14.0.
B					
Al-Cu-Ni-alloy	None	do	1,000–2,000	20	0.20 to 1.66.
Do	Phosphor bronze	do	2,000	19	8.75–45.0.
Do	Tin	6 hrs. at 520° F	2,000	19	60.0 (surface not galled but slightly scaled).
Do	Tin and phosphor bronze	do	2,000	19	Do.
Do	Silver and tin	do	2,000	19	60.0 (surface not galled and only slightly scaled).
Do	Silver and cadmium with tin as intermediate layer.	2 hrs. at 600° F. followed by 3 hrs. at 1000° F.	2,000	20	60.0 (no galling but considerable scaling).
Do	Silver and cadmium	6 hrs. at 420° F	2,000	19	60.0 (surface not galled and almost as good at end of test as at beginning).
Do	Silver and cadmium	10 hrs. at 750° F	2,000	20	60.0 (no galling but some scaling).

A designates a copper-nickel alloy.
B designates an aluminum-copper-nickel alloy.

These tests show conclusively that the novel product made by the present invention possesses remarkable bearing properties.

A second series of wear or galling tests was conducted on thrust bushings in a traversing gear box in comparison with a standard bronze bushing, under conditions where the aluminum-copper-nickel alloy could not be used without surface treatment. Table II summarizes the results of this series of tests:

Table II

Type of base metal	Layer metal	Thrust load	Lubrication	Cycles elapsed in test at rate of 85 per min. until first indication of galling occurred	Bonding or diffusion heat treatment
Standard bearing bronze	None	1,000	Castor oil	17,054	None.
Al-Cu-Ni alloy	Wiped tin	1,000	do	10,750	Do.
Do	Wiped 50-50 lead-tin solder.	1,000	do	4,977	Do.
Do	do	1,000	do	19,283	3 hrs. in molten solder at 1040° F.
Do	do	1,000	None	3,120	Do.
Do	Plated Cd	1,000	Castor oil	16,259	8 hrs. at 525° F.
Do	Silver solder	1,000	do	15,013	2 hrs. at 1050° F.
Do	do	1,000	None	5,391	Do.

The results of a third series of tests are given in Table III to illustrate the excellent and improved properties of a silver-cadmium surfaced, aluminum-copper-nickel alloy under conditions of sliding and/or rolling friction with heavy pressures and with and without lubrication. The silver-cadmium alloy contained 75–80 per cent of silver and 20–25 per cent of cadmium. For comparative purposes, results are included of one test on an aluminum-copper-nickel alloy, the face of which was not treated according to the present invention.

Table III

Example number	Thickness and finish of coating	Area tested	Pressure load	Type of friction at 140 two inch strokes per minute	Lubrication	Description	Results
		Sq. in.					
1	0.020 in. (machined finish).	2	1250 p. s. i.	Sliding	Light machine oil.	(*a*) 15 sec. under friction followed by 120 sec. "rest period" to dissipate temperature.	No failure.
1	do	2	do	do	do	(*b*) 60 sec. under friction and 20 minute "rest period."	Do.
1	do	2	do	do	do	(*c*) 6 cycles of 15 sec. of friction and 45 sec. of "rest."	Do.
2	0.001–0.002 in. (rough finish).	1	1000 lbs. per inch of roller length.	Rolling	Light machine oil.	(*a*) 142 sec. under friction followed by 80 sec. rest.	No failure.
2	do	1	do	do	do	(*b*) 13 min. under friction followed by 1 hr. rest.	Do.
2	do	1	1000 p. s. i.	Sliding	do	(*c*) 12 cycles of 15 sec. of friction and 45 sec. of "rest."	Do.

Table III—Continued

Example number	Thickness and finish of coating	Area tested	Pressure load	Type of friction at 140 two inch strokes per minute	Lubrication	Description	Results
		Sq. in.					
3	0.001–0.002 in. (rough finish).	1	1000 lbs. per inch of roller length.	Rolling	None	(*a*) 76 min. of friction	No failure.
3	do	1	1000 p. s. i.	Sliding	do	(*b*) 12 cycles of 15 sec. of friction and 45 sec. of rest.	Do.
3	do	1	2000 p. s. i.	do	do	(*c*) 12 cycles of 15 sec. of friction and 45 sec. rest.	Do.
4	No anti-galling coating machined. Al-Cu-Ni alloy surface.	1	1000 p. s. i.	Sliding	Light machine oil.	(*a*) 6 sec. of friction	Badly galled.

p. s. i. indicates pounds per square inch.

A fourth illustrative example of carrying the present invention into practice will now be described. A steel spline shaft, which worked as a machine element under very close tolerances and under considerable pressure, exhibited tendencies to gall and seize in spite of lubrication. The face of this steel spline shaft was provided with a thin 75–25 silver-cadmium alloy layer by means of the method of electro-deposition. This method was chosen because it seemed most convenient for the application. The results have been very satisfactory and successful and the steel spline shaft treated in accordance with the principles of the present invention has been in daily continuous service without any of the difficulties previously encountered.

An example showing the excellent resistance to corrosion of the novel product embodying our invention will now be given. An aluminum-copper-nickel alloy had a bonded 75 per cent silver–25 per cent cadmium surface and was exposed continuously in a 4 per cent common salt (NaCl) solution for two weeks. At the end of this period no evidences of corrosion were detected.

For the purpose of giving those skilled in the art a more detailed understanding of the invention, the following illustrative example will be given.

Roughening of faces preparatory to spraying

In order to provide the necessary anchorage for the coating, the bearing faces of the base metal are roughened by blasting. Experiments have demonstrated that a blasting machine known in the trade as a "Pangborn" and steel grit sold in the market as "Pangborn No. 30" are satisfactory. Other grit, such as silicon carbide and sand, may also be used. The roughening of the bearing faces is an important operation in the present process and great care must be exercised to insure satisfactory results. By following the appended precautions, the desired surface condition will be obtained. The air pressure used in the blast machine is as close to about 100 p. s. i. as possible and not lower than about 85 p. s. i. This is quite important in order to impart sufficient striking velocity to the grit. Adequate air filters should be installed and maintained in good working condition to clean the air. Similarly, the air should be dried. In practice the steel grit is preferably not larger than about No. 30 and not smaller than about No. 40. The former size is preferable since it provides deeper anchorage. It is important that the grit be kept clean and dry. It can be kept in such a condition by periodic sieving for the purpose of removing over- and undersize particles and by periodic washing of the grit in some solvent, such as carbon tetrachloride or alcohol. Care must be taken to prevent contamination of the grit during the blasting process. The blast nozzle should preferably have an orifice approximately ⅛" diameter. It should preferably be held in a "shaping" pencil, for ease in handling. It is preferred to hold the nozzle approximately one inch from the face to be blasted. Practice has shown that it is of the utmost importance that the abrasive stream be held at approximately right angles to the objective. Since the abrasive has a cutting action on the face it is being projected against, it is important that it be applied at a uniform rate of speed. In other words, the amount of abrasive delivered over any given area should be approximately constant, otherwise some areas will be under-cut, thus leaving a very unsatisfactory surface for bearing and anchorage purposes. The bearing faces can be uniformly roughened by the operator bearing in mind that unit time of blasting upon a unit area must be approximately constant throughout the blasting operation.

Cylindrical faces are preferably treated in a lathe and are rotated at moderate speeds. The abrasive stream is directed radially at the rotating face and slowly moved in a direction parallel to the long axis of the objective. In the case of flat or warped faces the parts are held in a clamp. The abrasive stream is moved slowly across the objective in one direction and then after roughening of the entire face the abrasive stream is moved over the face in a direction at right angles to its former path of travel. This will insure uniformity of the roughened face. In all cases particular care is taken to insure adequate roughening of the edges. It should be borne in mind that for best results the blasted face must be kept clean and must not be contaminated in any way. For instance, a finger brushed across it or even condensate from a person's breath may lead to unsatisfactory results. It is easy to prevent contamination if ordinary precautions are observed. The purpose of the blasting is to render the face of the bearing a checker board of hills and valleys or depression which provide adequate and effective anchorage for the coating.

After the face has been blasted it is carefully examined for imperfections and the latter are eliminated by re-blasting, if found. Finally the face is examined with a large magnifying glass and any pieces of embedded grit are removed with a clean sharp pointed tool. The blasted area is then dusted off with a high pressure air jet. The roughened face is now ready for application of the sprayed coating. This coating is applied as soon after completion of the blasting

operation as possible. In actual tests, it was found that the coating is preferably applied within the fifteen minutes following the dusting or cleaning with an air jet.

Metal spraying

In applying the coating by spraying the conventional metal spraying technique is followed. It should be mentioned that the oxy-acetylene flame is preferably maintained very slightly in a reducing condition to insure a minimum loss of cadmium from the silver-cadmium alloy by oxidation during the spraying operation. By employing the following features, sprayed coatings are obtained which are of a satisfactory nature.

The pressure for acetylene is about 15 p. s. i., for oxygen is about 15¾ p. s. i. and for air is about 60 p. s. i. Since pressure gauges are not always completely reliable, it is incumbent upon the operator to adjust the gases to obtain the proper type of flame. The speed of wire (No. 16 gauge) feed is about 8 feet per minute (approximately) and the distance of spray nozzle from the objective is about four inches (approximately). The stream of sprayed metal is preferably maintained as nearly perpendicular to the objective as possible. The thickness of the coating is made as uniform as possible and of the order of about 0.005''. A rapid preliminary pass is made over the whole face to be coated to insure good bonding. For best results, the application of the first thin coat on an uncontaminated face is important and is a prime factor in the subsequent strength of the bond. A bearing metal which has been used for coating the bearing faces and which has given satisfactory results, is a solid solution alloy of silver and cadmium (75% to 80% Ag. and 20% to 25% Cd.). This alloy has been found to have good bearing properties and good resistance to sea water corrosion.

Protection

The problem of protection must be considered both from the viewpoint of the parts being treated and from the angle of human safety. Since it is only desired to treat the actual bearing faces adequate precautions are observed to prevent harming of the exposed areas. Such protection is preferably provided by a combination of metal or wood templates and heavy blasting tape. The latter is much the cheaper method of protection and is used wherever possible. However, blasting tape cannot be used to advantage in cases where the abrasive stream impinges directly upon it for any period of time due to the fact that the tape is unable to withstand the direct impact and heavy cutting action of the steel grit. After a short interval it breaks down and seriously contaminates the roughened bearing face. Metal is preferably used for protection of areas not to be coated whenever direct impact of the steel grit must be withstood for more than a short period. In certain cases, such as protection of deep recesses in machined parts, wooden plugs may be used to advantage. In removing the templates or tape subsequent to blasting and spraying care is taken to avoid ripping of the over-hanging edges of the metal coat. After removal of the protecting material, it is quite important that these edges are immediately beveled down with a fine file to prevent future damage in handling. It is to be remembered that until the thick coat of bearing material has been machined down that it is rather brittle and particularly vulnerable at its edges. Protection tape (heavy Scotch blasting tape) was found to be very satisfactory. It is preferably warmed before use. Care is to be taken to avoid contaminating the adhesive-coated side either by touch or otherwise, as this has a deleterious effect on its adhesion to the metal surfaces.

With respect to the safety of the operator, there are two elements which are to be observed at all times. Whenever the blast machine is in operation even when the blasting is being performed in a closed box goggles are to be worn by the operator. A gas mask is to be used by the operator when spraying the silver-cadmium alloy. The spray sets up a fine dust and a certain amount of the cadmium is also volatilized with resulting possible menace to safety. The positive pressure type gas mask utilizing compressed air has been found very satisfactory. The hands of the operator are carefully cleaned after completion of spraying operations.

Heat treatment

After the parts have been blasted to produce a hill and valley surface on the foundation or base metal and the hill and valley surface sprayed, they are heat-treated for a period of about 10 hours at about 735° F. in a pure dry hydrogen atmosphere, and then allowed to furnace-cool. The foregoing treatment has a very definite beneficial effect upon the physical properties of the coating. This improvement is believed to be probably due to the combination sintering, intra-diffusion and reducing action within the body of the coat. It is believed that the bond at the base metal-coating metal interface is also improved to some extent. There is also the possibility that some of the cadmium that is volatilized during the heat-treatment impregnates the surface of the base metal ameliorating its anti-galling characteristics. However, good results have been obtained when parts were given no heat-treatment.

An indication of the effect of the heat-treatment on the cadmium content of the coat is demonstrated in the following table:

	Percent of
Cadmium in Ag-Cd wire	24.94
Cadmium in coat as sprayed	23.12
Cadmium in coat as heat treated for 10 hours at 800° F	22.05
Cadmium in coat as heat treated for 10 hours at 900° F	19.55
Cadmium in coat as heat-treated for 5 hours at 1000° F	19.90

Machining and final preparation of parts

The machining or dressing of the coated and heat-treated bearing surfaces is rather an important operation and is to be carried out with care. This can be readily appreciated by those skilled in the art since the tolerance allowed is only about 0.0005'' and since the coating may break down if improperly machined. For all cylindrical surfaces, the best method is to turn them down on a lathe. The work is to be rotated at a relatively high speed and the rate of tool feed is to be relatively low. The tool is to be sharp and pointed with a very slight radius on the point. It is to have considerable back rake. Experiments with many different tool steels indicated that the new "Momax" tool steel manufactured by the Cleveland Twist Drill Company was the most satisfactory. Flat surfaces should be prepared by grinding on a grinder capable of holding very close tolerances. A fairly soft wheel

is to be used. Warped, curved or complicated surfaces are to be filed down by hand with a fine file. All three of these dressing methods have given very fine results when properly carried out.

The type of finished surface desired is one in which the coat has been machined down until minute areas of the base metal start showing through the coat. In other words, a hill and valley structure in which the exposed tops of the hills are base metal and the valleys are filled with anti-friction metal. The coat is brought down until the area of exposed base metal is equal to about 20% of the total bearing surface. The ratio of the exposed base metal to the silver-cadmium coating that remains is therefore about 1:4. It is important that the finished bearing surfaces show a uniformly spotted or "leopard skin" effect. It is essential that the base metal "mountain or hill tops" peeping through the valleys filled with coating be finely and evenly distributed. The surface thus obtained gives an appearance in macro-structure similar to that of the typical bearing metal in micro-structure, i. e., a net-work or skeleton of hard grains (in this case of a nickel-copper alloy) surrounded by matrix or ground mass of soft plastic material (in this case Ag—Cd alloy).

When the treatment is not properly carried out, either due to unsatisfactory blasting or machining, there will be present large areas of exposed base metal with here and there a big patch of solid coating. This will possibly result in eventual failure of the bearing surface, either due to galling of the large exposed area of base metal or to scaling of the thick patches of coating or to both. Large areas of coating which show no characteristic spotting caused by the peeping through of the underlying base metal are to be avoided. The physical properties of these thickly coated areas have been found to be unsatisfactory. For this reason all bearing surfaces are preferably to be hand-filed before the production of an acceptable product. Any areas or edges which show the presence of a thick coating are to be filed down until the characteristic "leopard skin" effect appears. Since the edges are particularly vulnerable, it is quite important that they all be given a bevel and that no thick coating be allowed to exist in their vicinity. The thickness of the coating in its final form is in the order of magnitude of about 0.001". When manufacturing the parts to be subsequently treated. they are to be finished from about 0.0005" to about 0.001" below the tolerance specified.

Photomicrographs

Figs. 1 and 2 show desirable types of bearing surface. The light areas represent the layer of anti-friction metal, in this embodiment constituted of Ag—Cd alloy, and the dark areas depict the tops of the hills or projections on the roughened bearing face of the base or foundation stratum constituted of aluminum-copper-nickel alloy. These figures illustrate the desired spotted or mottled or variegated finished bearing surface.

Fig. 3 shows desirable type of cross section of bearing surface. The "mountains" or "hills" constituted of base metal are peeping through valleys filled with a coating constituted of the anti-friction metal.

Fig. 4 is similar to Fig. 3 and illustrates schematically the embodiment of the invention in which an intermediate layer is used to assist in bonding the outer layer of bearing metal to the base or foundation stratum. The intermediate layer, as described hereinbefore and as understood by those skilled in the art, should be capable of forming a diffusion bond between the layer and the base metals, i. e. should be a metal which alloys comparatively easily with the base metal and the bearing metal when exposed in intimate contact therewith at heat treating temperatures. Satisfactory results have been obtained, for example, using tin as the bonding metal between a base of aluminum-copper-nickel alloy and a layer of silver-cadmium bearing metal. Tin has also been used satisfactorily between the same type of base metal and bearing metal layers of silver and phosphor bronze. (See table on page 14.) The application or deposition of a plurality of layers of different metals to the roughened face of the base or foundation stratum produces, prior to the machining or dressing operation, an intermixed or agglomerate body having a plurality of irregular laminations or strata which become bonded to the base during the heat treating step. When the bearing surface is then dressed or machined by any suitable mechanical operations to reduce the bearing to required dimensions and to provide the required smooth surface finish, these irregular strata are cut or cross sectioned at various angles depending upon the angle of slope of the adjacent projection or hill to the surface. The finished surface thus comprises contiguous areas of different metal constituents of the bearing, producing a mottled or variegated bearing surface.

The foregoing description of the present process and the tabulations of experimental data will readily demonstrate to those skilled in the art that the invention represents a distinct and meritorious contribution to the art of high strength, corrosion-resisting alloys which are to be treated so as to provide a surface suitable for anti-galling or anti-friction conditions. In other words, a surface which is to be used for bearing purposes.

It is to be noted that the porous nature of sprayed metal coatings is distinctly advantageous with regard to their use as bearing surfaces. This porosity enables them to absorb a certain considerable amount of lubricating medium and hold the latter in reserve for periods in which, for one reason or another, the lubrication is not adequate. For example, the bearing on which a sprayed coating has been applied may be subjected to a vacuum to remove the air from the pores and then immediately immersed in a liquid lubricant under high pressure to impregnate the bearing with the lubricant.

Although the present invention has been described in connection with preferred embodiments, it is to be understood that various modifications may be made without departing from the spirit and scope of the invention as described herein and as defined in the appended claims. Thus, small amounts of other elements may be included in the silver-cadmium alloy to favorably influence certain of its properties, e. g., indium to improve corrosion resistance, and copper or nickel up to about 2% to improve the physical properties. In the foregoing description and the following claims the term "bearing face" is applied to the surface or surfaces of the base metal which is or are treated in accordance with the principles of the present invention to form a "bearing surface," the latter term desig-

nating the actual anti-friction and anti-galling surface of the bearing.

We claim:

1. The method of producing composite bearings composed of a tough, strong, corrosion resistant metal backing of nickel-copper alloy, and a bearing layer of silver-cadmium alloy bonded to said metal backing; said method comprising roughening the bearing face of said backing metal to produce numerous small irregular hills of the backing metal surrounded by shallow valleys over substantially the entire bearing face, coating said roughened face with a layer of the silver-cadmium bearing metal at least sufficiently thick substantially to fill the valleys to the tops of the hills, heat treating the coated backing metal to bond the bearing metal thereto, and machining the coated surface to smooth the same and expose the tops of the hills to the extent of about 20% of the total bearing surface whereby a composite bearing is produced having a smooth bearing surface comprising numerous small load supporting areas of the nickel-copper backing metal distributed over and amounting to about 20% of the bearing surface surrounded by an anti-friction matrix of the silver-cadmium bearing metal.

2. The method of producing composite bearings composed of a tough, strong, corrosion-resistant metal backing selected from the group consisting of nickel and nickel-containing alloys, and a bearing metal layer selected from the group consisting of silver, cadmium, copper, lead, tin, bismuth, antimony, and alloys thereof bonded to said metal backing; said method comprising roughening the bearing face of said backing metal to produce numerous small irregular hills of the backing metal surrounded by shallow valleys over substantially the entire bearing face, coating said roughened face with a layer of the bearing metal at least sufficiently thick substantially to fill the valleys to the tops of the hills, heat treating the coated backing metal to bond the bearing metal thereto, and machining the coated surface to smooth the same and expose the tops of the hills whereby a composite bearing is produced having a smooth bearing surface comprising numerous small areas of the backing metal surrounded by a matrix of the bearing metal.

3. The method of producing composite bearings composed of a backing member of nickel alloy and a layer of cadmium alloy bearing metal secured thereto comprising roughening the bearing face of said nickel alloy backing member to form a plurality of small irregular hills of the nickel alloy surrounded by shallow valleys over substantially the entire bearing face, coating the roughened face of the backing member with a layer of cadmium alloy bearing metal at least sufficiently thick substantially to fill the valleys to the tops of the hills and machining the coated surface to smooth the same and expose the tops of the nickel alloy hills, whereby a composite bearing is produced having a smooth bearing surface comprising a plurality of small areas of the nickel alloy backing member surrounded by a matrix of the cadmium alloy bearing metal.

4. The method of producing bearing surfaces comprising roughening the bearing face of a piece of base metal to produce a plurality of small irregular hills of the base metal surrounded by valleys, coating the roughened face of the base metal with bearing metal at least sufficiently thick substantially to fill the valleys to the tops of the hills, and machining the coated surface to smooth the same and expose the tops of said base metal hills whereby a smooth bearing surface is provided comprising a plurality of small areas of base metal surrounded by a matrix of the bearing metal.

5. The method of producing a composite bearing comprising providing a backing metal with a bearing face comprising a plurality of small irregular hills of the backing metal surrounded by valleys over substantially the entire bearing face, electrodepositing bearing metal on the bearing face at least sufficiently thick substantially to fill the valleys to the tops of the hills, and machining the electrodeposited metal to smooth the same and expose the tops of the hills whereby a smooth bearing surface is formed comprising the tops of said hills of backing metal surrounded by a matrix of said electrodeposited bearing metal over substantially the entire bearing surface.

6. The method of producing a composite bearing comprising providing a backing metal with a bearing face comprising a plurality of small irregular hills of the backing metal surrounded by valleys over substantially the entire bearing face, spraying bearing metal on said bearing face at least sufficiently thick substantially to fill the valleys to the tops of the hills, and machining the sprayed metal to smooth the same and expose the tops of the hills whereby a smooth bearing surface is formed comprising the tops of said hills of backing metal surrounded by a matrix of said sprayed bearing metal over substantially the entire bearing surface.

7. The method of producing a composite bearing comprising providing an irregular bearing face on a metal bearing back, said irregular face comprising a plurality of small metal projections forming a load supporting structure, tops of said projections extending at least to the required finished bearing surface; filling the spaces between said projections with bearing metal softer than the metal of said projections to a depth greater than required in finished condition; and reducing the composite bearing to the size required in finished condition to form a smooth bearing surface comprising tops of said projections surrounded by a matrix of said bearing metal.

8. The method of producing anti-friction and anti-galling composite metallic bearings which comprises depositing on the bearing face of a metal base a plurality of irregular layers including an under layer and an outer layer of different metals in an amount greater than required in finished condition, each layer being characterized by the presence of numerous small hills separated and surrounded by valleys, and reducing the size of the composite bearing to that required in finished condition and to provide a smooth surface comprising numerous small areas of the metal of an under layer surrounded by the metal of the outer layer.

9. The method of producing anti-friction and anti-galling composite metallic bearings which comprises roughening the bearing face of a metal base to provide numerous small hills separated and surrounded by valleys, depositing a plurality of irregular layers including an under layer and an outer layer of different metals onto said roughened face to a thickness of deposited metal greater than required in finished condition, and machining the composite bearing to reduce it to the size required in finished condition and to provide a smooth bearing surface comprising numerous small areas of the metal of an under layer peeping through the outer metal layer.

10. A method of producing anti-friction and anti-galling composite metallic bearings which comprises depositing on the bearing face of a metal base a layer of metal having an irregular outer surface made up of numerous small metal hills separated and surrounded by valleys, depositing different metal on said layer in an amount greater than required in finished condition, and then reducing the size of the composite bearing to that required in finished condition and to provide a smooth bearing surface comprising numerous tops of said metal hills surrounded by said different metal.

11. The method of producing a composite anti-friction and anti-galling metallic bearing comprising providing a metal base with a plurality of small metal projections extending from the bearing face thereof, to form an irregular surface, filling the spaces surrounding said projection with at least one layer of bearing metal, and smoothing said bearing to provide a bearing surface comprising separated areas of said small metal projections surrounded by said bearing metal.

12. A composite metallic anti-friction and anti-galling bearing which comprises a metal base, a plurality of small irregular spaced metal projections extending from the bearing face of said base, bearing metal filling the spaces surrounding said projections, said bearing being provided with a smooth bearing surface comprising separated areas of said small metal projections surrounded by said bearing metal.

13. A composite metallic anti-friction and anti-galling bearing which comprises a stratum of metal having an irregular outer face, and at least one layer of different metal applied to the irregular outer face of said stratum and machined down until projections on the outer face of said stratum extend through said layer to provide a smooth bearing surface comprising areas of the metal of said stratum surrounded by the metal of said layer.

14. A composite metallic anti-friction and anti-galling bearing comprising a stratum of metal having an irregular outer face, and a layer of a different metal softer than the metal of said stratum applied to the outer face of said stratum and machined down until minute projections on the outer face of said stratum appear in the smooth bearing surface as minute separated areas surrounded by said layer of softer metal.

15. A composite metallic anti-friction and anti-galling bearing which comprises a stratum of metal having an irregular outer face, and a layer of metal different from the metal of said stratum electroplated onto the irregular face of said stratum and having a smooth bearing surface comprising separated areas of the metal of said stratum surrounded by said electroplated metal.

16. An anti-friction and anti-galling metallic bearing having a smooth composite bearing surface, a major portion of said bearing surface consisting of relatively soft bearing metal and a minor portion of said bearing surface being made up of a plurality of small separated islands of macro-character and of relatively harder metal forming a load sustaining structure comprising metal supports extending from said bearing surface to an under stratum of metal, said small separated islands of relatively harder metal being surrounded by said soft bearing metal.

17. A composite anti-friction and anti-galling metallic bearing which comprises an under stratum of metal, a layer of relatively soft bearing metal mounted on said under stratum, a plurality of small load supporting metal projections extending from said under stratum through said bearing metal, thereby providing a bearing having a composite bearing surface comprising a plurality of small islands of load supporting metal surrounded by a matrix of said bearing metal.

18. A composite metallic anti-friction and anti-galling bearing comprising a layer of base metal and an adherent layer of bearing metal keyed to the base metal by a plurality of irregular projections of small cross-sectional size spaced at random on the base metal and extending through and surrounded by the layer of bearing metal to form a minor part of the bearing surface.

19. A composite metallic anti-friction and anti-galling bearing having a bearing surface comprising a plurality of separated irregular macroscopic islands of base metal constituting a load supporting structure surrounded by a matrix of bearing metal, said islands of base metal forming a minor portion of said bearing surface and said matrix of bearing metal forming a major portion of said bearing surface.

20. A composite metallic anti-friction and anti-galling bearing comprising a metal base possessing strength but deficient in anti-friction and anti-galling properties, an adherent layer of bearing metal keyed to said base metal by a plurality of metallic projections of irregular small size and random distribution extending from the metal base through the layer of bearing metal to form a bearing surface comprising a plurality of separated islands of the metal of said projections constituting a load supporting structure surrounded by a matrix of bearing metal.

21. A composite metallic anti-friction and anti-galling bearing comprising a body having irregular strata of metal bonded to each other and to the roughened bearing face of a metal base and provided with a smooth outer bearing surface comprising numerous small areas of said metal base and under stratum of metal peeping through and surrounded by the outer stratum of metal.

22. A composite metallic anti-friction and anti-galling bearing comprising a machined metallic body of irregular strata bonded to each other and to the surface of a metal base, said bearing having a variegated bearing surface comprising numerous small exposed portions of an under stratum of metal peeping through and surrounded by metal of the outer stratum.

23. A composite metallic anti-friction and anti-galling bearing comprising a metal body having a plurality of irregular layers of different metals bonded onto the surface of a metal base, and provided with a smooth bearing surface comprising a plurality of small areas of an under layer of metal peeping through and surrounded by the outer layer of metal.

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