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METAL COATING PROCESS

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This invention relates to the mechanical welding or attachment of small particles of metal to one another or to a metal surface. More specifically it relates to the mechanical and physical conditions securing the union of large numbers of metal particles to a metal surface whereby a dense metallic coating or cladding of the metal surface results, without the employment of either electricity for electrodeposition, or of externally applied heat sufficient to melt the plating metal.

This invention is a continuation-in-part of application for U.S. patent, Serial Number 3,537, filed January 21, 1948, now Patent 2,640,001, issued May 26, 1953. The invention of this prior application involves the use of films such as oily or lubricant films in promoting and securing the individual attachment or weldment of small particles of metal which are subjected to distortive pressures by impact or otherwise to the surface of articles to create useful metal coatings on the articles.

It is well known by those skilled in the art that the presence of any oil or grease is highly detrimental to electroplating, soldering, brazing or any metal joining operations. It is customary in some metal joining operations to use a flux such as zinc or ammonium chloride which is the exact opposite of the organic films used for instance in the disclosure in said prior application, Serial Number 3,537. The method hereinafter disclosed is thus entirely unique and different in its employment in the welding or joining of metal surfaces of thin organic films as an aid in uniting metal.

It is already known to apply metallic coatings to articles by placing the articles within a ball mill containing comminuted hard material such as sand together with the metal to be applied in the form of dust or powder with or without a liquid; it is possible in this way to apply to the surface of the article extremely thin coatings of the metal dust or powder which coating is commonly known as a smear coating. Such coating although adherent is so thin that it provides little or no protection against corrosion and at best is suitable only for indoor or temporary use.

With all such known methods as hitherto practiced, however long the articles are agitated or tumbled within the ball mill, it has not heretofore been found possible, so far as I am aware, to increase the thickness of the applied coating beyond the extremely thin smear aforementioned so that as above stated such coatings are of little or no value. Coatings of the prior art are characterized by their creators in such terms as "a color," "infinitely thin," "must be immediately protected by a lacquer," "very thin," a coating good for "storage, transit, or indoor use," and "almost molecularly thin." It is not difficult to smear a soft ductile metal such as lead, zinc, brass, silver, etc. in the microscopic surface irregularities of a harder metal such as steel.

It is also old in the art to tumble metal articles in ball mills with all manner of hard and abrasive materials such as iron shot, metal slugs, leather chips and sand either dry or admixed with a liquid such as water, soap solutions, stale beer and all manner of proprietary compounds for the purpose of deburring, descaling, polishing and burnishing. These processes and the liquids and materials used, thus remove metal, they do not apply metal. In spite of the experience in the arts in barrel finishing

and in the application of smear coatings, no way has hitherto been known to apply substantial metal coatings of controllable thickness mechanically in which a cohesive bond is established between particles already adhered to the surface by the adhesive bond and fresh metal particles, whereby the coating is built up incrementally particle by particle to desired depth of coating.

This disclosure, as hereinbefore stated, deals with the use of adherent organic films applied to the metal surfaces to be joined prior to their union by means of mechanically applied forces. As stated the use of such films is entirely unexpected and is entirely novel and outside all of the generally accepted principles of those skilled in the arts to use organic films, to aid in the build-up of substantial coatings of desired thickness.

The instant disclosure explains why and how such organic films function in promoting the weldment or union of metal surfaces.

A further object is to predetermine and limit the thickness of said films on the metal surface.

Another object is to explain the critical nature of the ratio between the area of new metal formed when a metal particle is drastically deformed and the thickness of the film covering the particle prior to its deformation.

Another object is to show how the type of surface of the different metals plays a part in the mating of metallic surfaces.

Still other useful objects will be disclosed hereafter in which the physical properties of the film most suited for plating will be disclosed.

The instant invention is concerned with the physical properties of the films rather than with the chemical nature of said films and the various classes and kinds of chemicals useful in filming and cleaning the metal surfaces as disclosed, for instance in my co-pending U.S. patent applications, Serial Numbers 3,537, filed January 21, 1948, 176,782, filed July 29, 1950, now Patent 2,689,808, issued September 21, 1954, and 221,535 filed April 17, 1951, now Patent 2,640,002, issued May 26, 1953, and reissued August 31, 1954, Reissue 23,861.

I have discovered that the critical physical properties of the film are provided by hundreds of film forming substances which are effective in promoting the union or welding of mating metal surfaces. These film forming substances are from different chemical families, but they have one property in common, namely their ability to film a metal surface and interpose a physical barrier between the metal surface and its environment.

It is known to those skilled in the art that a metal surface is oxidized long before the oxide film becomes thick enough to be visible to the naked eye. Using copper as an example it is known that to be visible on the surface of brightly polished copper the oxide film must be approximately 70 angstrom units thick, while oxide films on copper surfaces have been measured that were only three angstrom units. The last measurement approximates the atom size of oxygen and has been observed to form instantly on such a tarnish resistant metal as copper. Metal surfaces in ordinary environments containing oxygen are oxidised regardless of whether or not any tarnish or oxide film is visible. Such oxide films are instantly created on any clean metal surface and interpose a physical barrier to the welding or union of metal surfaces brought into contact with one another.

It has been shown that when a piece of steel is broken under the surface of clean mercury and instantly joined together, the broken ends will knit to form a strong joint. If the same piece of steel were broken in air and then instantly plunged under the surface of the mercury the broken ends will not knit. Those skilled in the art know that the oxidation of a piece of metal occurs instantly when it is exposed to air.

It is known that oxygen from water vapor is particularly effective in promoting oxidation of metals.

In the practice of the instant disclosure the organic filming agent may be dispersed in water in admixture with the fine metal dust of the coating metal. Normally a relatively vigorous reaction occurs between water and finely divided metallic protective dusts such as zinc, aluminum, magnesium, etc. The organic film of the instant disclosure thus serves to insulate the metal surfaces from water or other fluid.

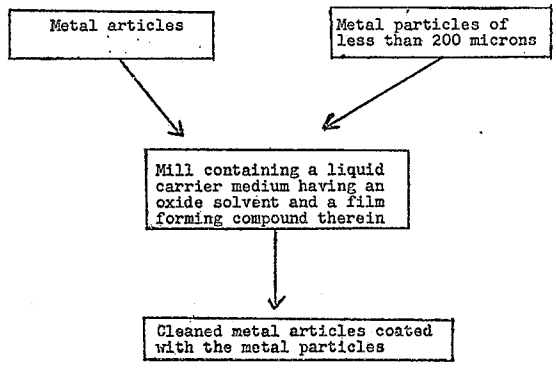
It is known that mechanical attrition or rubbing will clean and remove oxide films which instantly reform unless the surfaces so cleaned are protected. I have found that such protection is afforded by the physical barrier created on a metal surface by a lubricant or adherent continuous organic film of suitable thickness. When such lubricant film is squeezed out by pressure or heat, galling or welding between sliding metal surfaces will occur when oxygen cannot reach the mating surfaces. The strength of welds created in this manner by physical contact between clean metal surfaces is sufficient, to cause pitting of the metals in sliding contact, that is to say, actual holes are torn in the metal because the weld is equal to the forces which normally act to hold a metal together. Familiar examples of this are in the seizing of machinery when lubrication fails.

In contrast to the instant method the seizing or galling takes place between massive metal surfaces such as machinery and is extremely inefficient, because with the machinery the actual percentage of the total surfaces in contact that are close enough to weld is extremely small. Large surfaces of metal even when polished to a mirror smoothness are rough and irregular and full of mountains and valleys when viewed at high magnification or when considered in relation to the size of the atoms involved. Welding takes place with large surfaces when the high or protruding areas of one surface engage similar high areas of the other. The actual area of metal that welds in cases of this sort is generally in the order of 10 percent of the total area of metal in contact.

In my method a very high degree of efficiency is obtained because at least one of the two metal parts to be joined or united is extremely small. In the practice of the invention I prefer to use a metal dust of the coating metal which has an average particle size of 1 to 20 microns. Particles of this size are more easily laid down and incrementally welded into the coating. Larger particles when used may be broken down to this size before they are deposited in the coating. These small particles are plastically deformed, flattened or crushed in the welding operation so that intimate metal to metal contact is secured over the whole area of the welded surfaces and the area of the weld is a much larger percentage of the contacting surfaces.

When a small particle of metal is deformed or crushed its surface is increased and new metal previously in the interior of the particle is brought to the surface. The protective physical film used in the instant process that encases the particle is ruptured and will not reform over the new metal surface created, if the thickness of the film does not exceed certain limits to be hereinafter described. The new metal surface created by the flattening of the metal particle is produced at the area of maximum pressure so that the ruptured film is forced outwards and the clean new metal formed under pressure against another metal and surrounded by the outwardly flowing ruptured film does not come into contact with oxygen in any form and welding of the newly formed surface ensues. As the forces that bond the organic film to the metal are not as great as those that hold the metal itself together the film is parted from the metal when the applied pressures rise to the point at which the metal itself begins to flow. Thus the protective film is always present as a tightly adherent physical barrier until it is removed only at those areas in metallic contact where welding can ensue. As the metal particle continues to deform the pressure and the forces of capillarity combine to continue squeezing out the intervening film and welding of the remaining surfaces which are thus freed of film, can occur, if the underlying metal is free of oxides. Heat generated in the particle by the mechanical work done in distorting the particle is available to further assist the weld or union.

Having described the objects of this invention and the general principle employed in its execution, I will now describe the invention with more particularity and set out the limits hereinbefore referred to, as shown by the following flow diagram:



Essentially, this subject process is for joining metal particles irregular in shape but in general approximately spheroidal in shape, having an average particle size of less than 200 microns diameter, selected from the nonrefractory group of metals and consisting of either tin, lead, indium, cadmium, magnesium, zinc, copper and silver or consisting of any admixture of this group of alloys of these metals one with another or one with others, to one another and to any other metal surface.

Metal dusts that are condensed from the vapor of the metal almost invariably condense in the form of small droplets and are thus spheroidal in shape. Metal dusts formed by air disintegration are generally extremely irregular in shape with the exception of copper which breaks up into spheres. The brasses in powder form made by air disintegration vary from round to irregular depending on the copper content of the brass.

Particles of metal that are very irregular in shape tend to break up into roughly round particles when subjected to an abrasive mechanical scrubbing action such as that obtained by tumbling in a ball mill.

As used herein the phrase "substantial round particles" is intended to mean both round and those very irregularly round metal powders which result from air disintegration.

The process consists of encasing the metal particles and the metal surfaces, which are to be united to the particle, with an organic film which is unreactive to, by, or with the metal of the particles or the metal surfaces. Said organic film is of a thickness between 0.1 and 100 microns and such as to allow the approximately spheroidal particles to be brought into close proximity to one another or close proximity of the metal surfaces by their natural mechanical or chemical attraction, gravitational settlement, externally applied force or combination of these attractions or forces to within 2.0 microns.

This process consists also of the action of mechanical forces whether they be due to the momentum of the particle, or to an externally applied force, the direction and magnitude of which are sufficient to cause the particles to come into intimate point contact and to alter the shape of the spheroid to an exceptionally oblate spheroid or ellipsoid and to reduce the thickness of the particle to a maximum thickness which is one-half of its original thickness and to reduce the thickness of the organic film to a minimum of .1 micron. The surface area of said particle is thereby increased so that new

metal to the extent of a minimum of one-third of the original surface area is exposed. This new metal surface being clean and unreacted and possessing a high free energy at the moment of its formation will bond to any clean metal surface with which it is in contact.

In this final stage of the process the film in consequence of its large molecule size and its surface tension, is either excluded from the metal by extrusion, or the metal surfaces weld together all around it and it pulls itself into a globule the diameter of which will generally be larger than .1 micron.

To illustrate these points the minimum thickness of the organic film prior to sufficient mechanical action to cause welding of the particles was determined by examination of the coating structure on corrugated fettering nails wherein the coating inside the corrugations consisted of spheroidal particles, not welded together but separated by an organic film. The average thickness was measured to be 1.4 microns. The maximum thickness of the film is dependent upon the volume ratio of particle to organic when the distribution is uniform, that is if the particles have not been brought together by their natural mechanical or chemical attraction, gravity settlement externally applied force, etc.

The film is thus of such nature as to allow the particles to be brought to within 2 microns of each other as noted from the study of the uncompacted coating shown in the photomicrographs discussed.

The organic filming agent is preferably dispersed in solution or as a fine emulsion in any liquid unreactive with the filming agent. The function of the liquid carrier is to distribute the filmer uniformly all over the metal surfaces to be joined. It is a property of filming agents that they tend to exhaust themselves on solid surfaces. If such filmer suitably dispersed in a liquid is agitated with the metal particles and article surfaces then the organic filmer will be uniformly distributed all over these solid surfaces. The adhesion of this film is believed to be tighter on clean metal surfaces than it is on those surfaces which are oxidised. Mechanical forces of abrasion or attrition with or without hard material will tend to scour or clean especially the oxidised areas. Chemical solvents for the oxides may be present to assist the mechanical action in removing unwanted oxide or adsorbed contaminant films. The organic film reforms on such areas as they are cleaned.

In further explanation as the clean particles or the clean particle surfaces are brought into contact under pressure, the organic film is pushed aside so that metal contact is made at the point of tangency. However, as pressure is increased or is maintained sufficient to cause plastic flow, the particels will be flattened and since the organic film is not as strong as the metal and yet possesses a high surface tension, it is progressively pushed away, or from between the areas of surface contact (except in special cases to be noted later). It therefore follows that as the particle is flattened, the surface area must increase, since the volume is constant and a sphere imposes the smallest surface area to volume ratio for a given volume. It is therefore important to note the location of the new area exposed. As the particle plastically flows in a direction of non-restricted motion, part of the force is resolved into a tensile force on the surface, which force is sufficiently great enough to cause the plastic flow of the surface of the particle. However, since this tensile force is really a series of forces around the periphery of the particle and also a point at the center, the resultant maximum plastic strain would be in the close proximity of the point of contact. The new surface is exposed at the points where contact is being made and consequently the particles weld instantly at these points. As deformation proceeds, the point of contact becomes an area contact. However, since the new area will always be protected by the area of surrounding film, the new area will still be in a condition for welding. Nevertheless, since the contact angle at this new area is decreased, the probability of the organic film being incorporated between the particles is increased.

Thus, it is impossible to incorporate the organic film between the surface at or near the points of initial contact. However, the particle surface can be expected to have a non-smooth surface by virtue of scratches and "pockets" or "dimples." Any organic film incorporated in a scratch may be withdrawn by capillary action if the scratch extends out of the area of contact. Any organic film incorporated in a "pocket" or "dimple," however, will more than likely be sealed off if it approaches in size or is smaller than the area of contact. It should be noted that these types of discontinuities of surface will be more prevalent in the area of initial contact than in the areas of final contact for although the exposure of new area at the point of contact will be greater at the point of original contact, the latter areas will have plastically flowed more and (excluding deformation marks) the surface discontinuities should be erased.

Hundreds of microphotographs have been taken of coatings laid down by this method and these show that the inclusions exist in globules either in the interior of large grains formed from a number of particles or concentrated at the boundaries between smaller grains. The encasing organic film while tightly adherent to the metal is not as strong as the metal and when the metal surface plastically deforms and flows the organic film is broken and parted, new clean metal is brought to the surface from the interior of the plastically flowing metal and such new metal is completely protected from oxygen by the adjacent metal surfaces and by the outwardly moving organic film so that welding ensues and residual film is retained in traces in the coating in the form of globules particularly at grain or particle boundaries. Where the nature of such film, inert to the metal, is protective then the inclusion of such organic films in the resultant coating in minute traces is beneficial and enhanced tarnish resistance and better protection against corrosion are the result.

The ability of clean surfaces to weld together is not limited to any particular metal, in fact it is not even limited to metals. The adhesion of freshly blown glass fibers to one another or to metal is well known. It is well known that two lumps of clay when brought together will adhere and eventually coalesce. All metals when properly clean will weld to any other metallic surface that is equally clean, provided that proper contact on an atomic or molecular scale exists.

As a practical matter metals differ from one another in hardness, ductility, etc. so that it is much easier to cause plastic flow in a metal like lead than, say, in one like chromium. The ease with which the metal will flow plastically under pressure has a direct bearing on the ability of metal surfaces brought together to make perfect contact with one another.

When two ductile metals are brought together, joining or welding of the two surfaces will be easier to secure than when two very hard non-ductile metals are involved. Two ductile metals will be easier to weld together than one ductile and one hard metal. However, as long as one of the surfaces to be joined is ductile and flows readily under pressure the second metal can be any metal having a clean surface. Consequently while all metal surfaces are amenable to welding, it is much easier to weld two metals when one of the metal surfaces is a ductile metal.

This disclosure deals with the use of organic films to protect the metal surfaces against oxidation and surface contamination. Other means may be used to protect metal surfaces from oxidation; plating may, for instance, be done in a vacuum or inert atmosphere under conditions that will clean the surfaces of oxides and contaminant films. In a vacuum or inert atmosphere such film cannot reform. This application of the process is

described in the co-pending U.S. application, Serial Number 156,936 to Pottberg and Clayton, and now Patent No. 2,723,204.

Certain of the metals such as lead, tin, cadmium, indium, zinc, magnesium, aluminum, copper and silver, and their alloys with one another and with other metals, are particularly suited for plating with the use of the organic films of this disclosure. While these metals may also be plated by the method of Pottberg and Clayton described above, it is frequently preferable to employ the organic films of the instant disclosure. The thickness of film employed is so small that the quantity of filming agent used in filming is very small and the process is simple and inexpensive in operation and the coatings produced are lustrous and dense.

This invention shows what has never been recognized before, namely that it is the type and character of the adsorbed film that is of determinative importance and that it is the presence of oxide films on metal surfaces and the adsorbed gases and vapors that exist on all such surfaces that prevent adhesion. The disclosure herein made shows that such gases and vapors must be displaced by a strongly adherent organic film that will also prevent oxidation from recurring on the metal surfaces to be joined after it is removed by chemical or mechanical means. The use to assist in the joining of metal surfaces of an organic barrier film having the physical properties hereinbefore described is thus radically new in concept and practice from all of the prior art.

The method of removing such organic barrier film, by mechanically distorting one or both of the metal particles, so that clean metal is exposed at the common metal interface, which allows the forces of adhesion to aid the mechanical forces to increase the area of contact, and to aid in forcing out the barrier film, when it is no longer required to shield the mating surfaces from the outside oxidising environment, is also new. The forces of adhesion are proportional to the area of contact so that as deformation of the particle by the mechanically applied distortive forces proceed, the area in contact is increased, and thus the force of adhesion is further increased, and this in turn leads to still greater deformation, the process continuing until the metal surfaces are entirely united and the barrier film has been removed as hereinbefore described. The mechanical distortive force thus needs only to start the welding operation which can continue, if the metal particle is small enough through action of the large distortive forces exerted by the powers of adhesion.

An initial innermost layer of small particles at the plated surface is thus driven into intimate metal to metal contact with the said surface and bonded thereto by mechanical and atomic forces. Then the particles are impacted onto these innermost particles and bonded thereto in metal to metal contact in continuing deposits overlapping and interfitting in a most intimate surface to surface relation giving a layer-like formation of the coating with the flattened particles overlapping and interengaging like shingles; and it is this structure that develops the persistence with which the coating maintains its general form and adherence to the base metal. With the metal particles thus surface-worked in the tumbling or other operation, the particle surfaces develop a high free energy because of the decreases in the volume of the strain free matrix which in the resultant intimate metal to metal contact with each other at the areas of interfitting there appears to be some recrystallization which in some cases merges grain boundaries. Some particles apparently grow rapidly in size with resulting grain growth across the particle boundaries so that individual smaller particles amalgamate into larger grains. A crystalline growth of the particles may thus proceed from particle to particle across the interfaces and such recrystallization of the worked particles when initiated continues during the treatment and subsequently may be accelerated by heating after the particles are removed from the barrel.

The physical limitations of the barrier film for best results have been described and have been set out in the claims. Organic films of the dimensions and physical properties hereinbefore described will always work. Films preferred to give the desired characteristics are the cationic and nonionic film forming oils. The cationic organic oils in particular are especially well adapted to exhaust themselves on solid surfaces with which they come into contact. Among other types of films that have served especially well are the natural and artificial gums as gum acacia and sodium carboxy methyl cellulose and the marine gums such as the alignates derived from kelp. Besides the gums all of the film forming fatty acids both saturated and unsaturated work when in solution in a suitable carrier liquid. From the fatty acids may be derived hundreds of strong film forming derivatives, many of which are water soluble, particularly suitable are the long chain tertiary amines solubilised with ethylene oxide.

The amines are organic alkalies and may be neutralized with an acid to form an amine salt. For example, any fatty acid may be neutralized with a fatty amine to form a fatty salt. To illustrate an oleic acid amine may be neutralized with acetic acid to form the fatty acetate. These organic salts formed in this way are excellent filming agents for use in the practice of the invention. In general a slight excess of the acid over that required for neutralization is used to provide for the chemical solution of the oxide films occurring on the surfaces of the metal powders as has previously been described. Further examples are an organic salt formed by the neutralization of an organic alkali with an acid such as a fatty acetate and amine citrate and an amine adipate. Instead of water the inert liquid vehicle may be for instance an organic compound such as hydrocarbons, ketones, fluid alcohols, ethers and aldehydes.

I do not desire to be limited in any way whatsoever to any particular type of organic film except by the physical limitations specified in the claims. The above listed compounds are intended to serve only as illustrations of the many hundreds of such organic film formers capable of giving the proper physical characteristics to the film.

The use of an inexpensive inert carrier liquid to distribute the very small amount of film former, either in solution or in emulsion, over the surface to be filmed is also new and novel.

The limitations which have been described are sufficient for those skilled in the art to operate the process. While I do not wish to be limited in any way to any particular type or form of apparatus which will serve to crush the particles to the extent indicated and weld them to the surface of other materials; a very convenient way of practicing the invention is to tumble in a rotating mill or other similar device, for example, to zinc plate 100 pounds of small tacks, these tacks would first be cleaned in any suitable way such as by tumbling them in sand with a little water or by a light acid pickle and then agitating them with zinc dust and the film forming material and a reagent to assist in the removal of oxide films. To illustrate further: 100 pounds of tacks (preferably cleaned), 5 gallons of water, 120 grams of a water soluble long chain tertiary fatty acid amine sold commercially under the trade name of Ethomeen C/60, 300 grams of citric acid, 10 pounds of zinc dust agitated in a closed revolving mill, 18 inches in diameter, 24 inches long for 3½ hours at 38 r.p.m. In the above illustration the rolling action of the tacks provided the mechanical forces necessary to secure the distortion and subsequent weldment of the particles in the manner described. The mechanical rolling action also served to distribute the film forming material which is water soluble through the entire mass of the entire charge and to coat each of

the tacks and the particles of zinc as described. The action of the water serves to distribute the filming agent over the metal surfaces and the citric acid serves as an aid to the mechanical scrubbing in removing and dissolving metal oxides.

It is evident, of course, that there are large numbers of organic compounds applicable as film formers in accordance with this invention to completely encase the fine powder particles with a thin protective layer less than 100 microns in thickness and operative to permit penetration and displacement, as described, under the mechanical forces reducing the particles to only a fraction of their original thickness. Various examples are set forth in this and my co-pending cases. Other organic compounds similarly acting as film formers in the same way are readily useable to the same effect and the process is not confined to any specific examples but is intended to cover the physical combinations and operations as described in this and my companion cases and set forth in the following claims.

I claim:

1. A process for joining and uniting metal powder particles of substantially spheroidal shape and selected from the non-refractory group of metals consisting of tin, lead, indium, cadmium, magnesium, aluminum, zinc, copper and silver and of alloys of these metals with each other, to one another and to the surfaces of metals, said process comprising providing in contact with the metal surfaces to be coated a mass of said metal powder particles of spheroidal form in admixture with a liquid carrier medium, said particles being less than 200 microns in diameter and surface filmed with oxide and said liquid carrier medium containing a compound acting as a solvent for said oxide filming, applying forces of impact and attrition between the particles and between the particles and the surfaces to be coated to scour and clean the surfaces of said particles and surfaces to be coated and remove oxide filming therefrom and forthwith as each surface is cleaned, covering said cleaned surface with an organic film forming compound unreactive with said cleaned surface, said organic film covering the cleaned surfaces to a maximum thickness of less than 100 microns and being effective to create a physically continuous barrier excluding oxygen from said surfaces and subjecting said film covered particles and surfaces to be covered to mechanical impact and attrition forces of sufficient magnitude to reduce the average thickness of each particle to less than one-third the original maximum thickness and thereby to increase the surface area of said particles while at the same time reducing the film thickness so that it is cleared from portions of the expanded metal areas of the particles and contacting areas of the metal surfaces to be coated, and welding said cleaned and film cleared areas to similar metal surfaces with which they are in contact.

2. The process as set forth in claim 1 in which there is a cationic organic film former having the specified characteristics to film the metal surfaces to be joined.

3. The process as set forth in claim 1 in which there is a non-ionic organic film forming material having the specified physical characteristics to film the metal surfaces to be joined.

4. The process as set forth in claim 1 in which there is water as a carrier liquid to distribute the organic film former having the specified characteristics over the metal surfaces to be joined and the organic film former is water soluble.

5. The process as set forth in claim 1 in which a carrier liquid is provided by water having a pH between the limits of 1 and 6.

6. The process of protectively coating metal surfaces of articles with a plurality of layers of metal particles as set forth in claim 1 comprising subjecting the surfaces of said articles to impacting by other articles in the presence between them of powder particles of ductile metal below 100 mesh in size so that the individual powder particles are caught between said articles and crushed into flattened leaflike shape in metal to metal contact and adhesion with the said article surfaces, continuing said impacting and further flattening of said particles and forming tightly adhering bonds between them and the article surfaces and add other flattened metal particles overlapping and interfitting flatwise like shingles in successive layer formation with their long axes conforming generally to the direction of the adjacent surfaces and in metal to metal contact and cohesion with each other securing each particle in place by intimate metal to metal bonding permitting incident recrystallization across boundaries between the particles, and repeating said particle layer formations to desired depth of coating under said continued impacting and crushing of said particles.

7. The process of protectively coating metal articles to desired thickness as set forth in claim 6 in which the powder particles have thin organic coatings which are penetrated and displaced by the impacting and crushing of the particles to bring the article and particle surfaces into metal to metal contact.

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