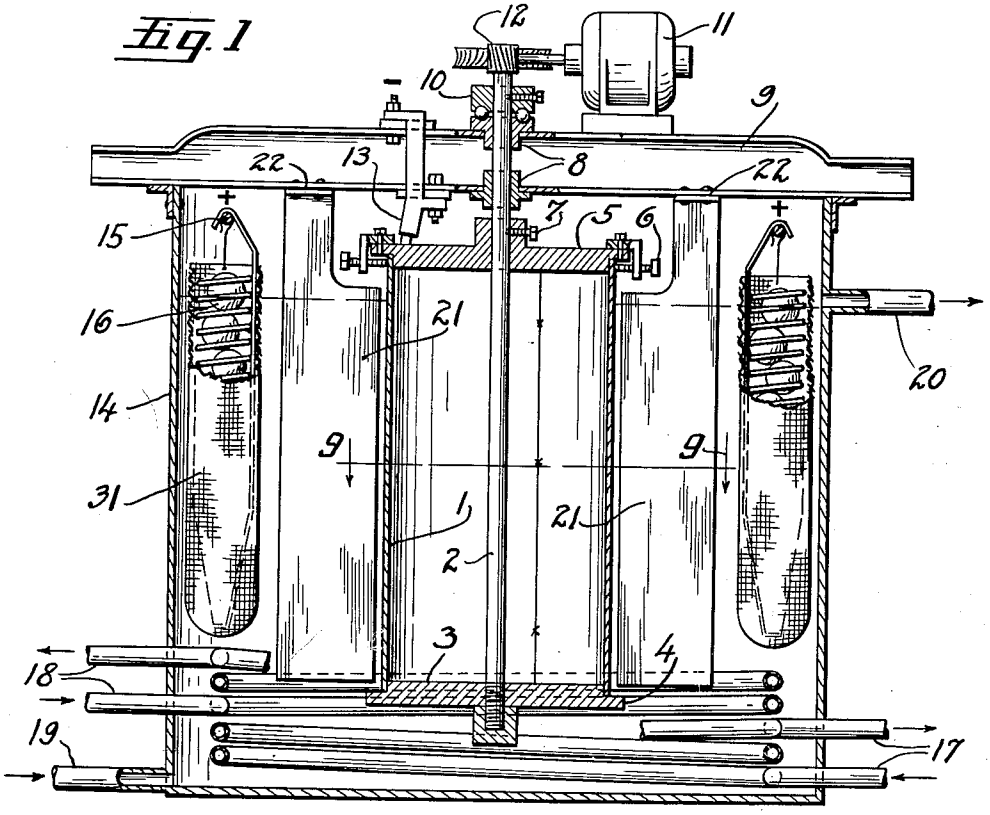
Feb. 8, 1938. K. G. SODERBERG ET AL 2,107,806

DUCTILE CADMIUM COATING

Filed June 3, 1936 3 Sheets-Sheet 1

Fig. 1



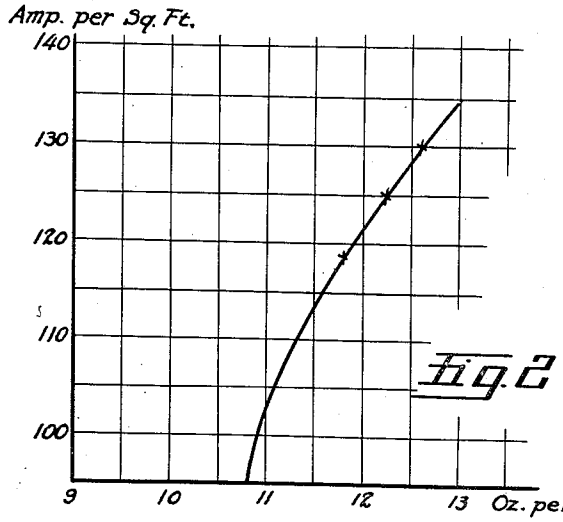


Fig. 2

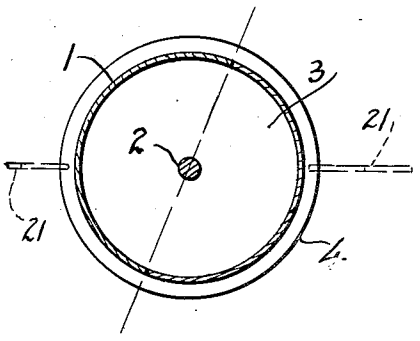


Fig. 3

Composition:-
13.5 Oz. per Gal. free Na CN.
40 Ml. per L. Triethanolamine,
.06 Gr. per L. Nickel.
Temperature:- 40° Centigrade.
Surface Speed:- 450 Ft. per Min.

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DUCTILE CADMIUM COATING

Filed June 3, 1936 3 Sheets-Sheet 2

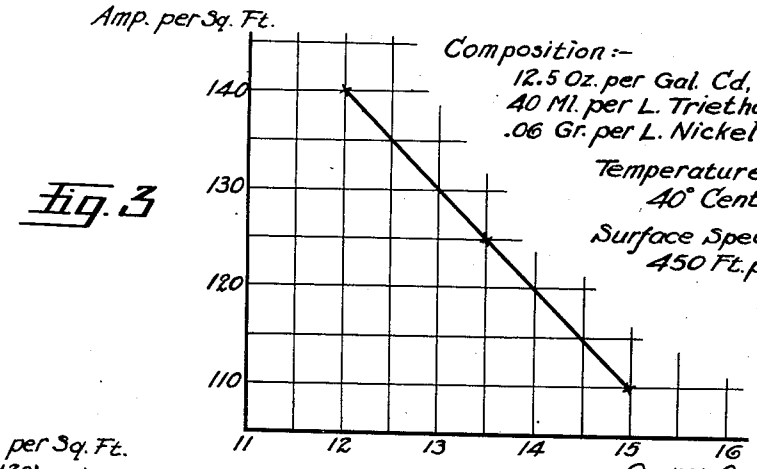


Fig. 3

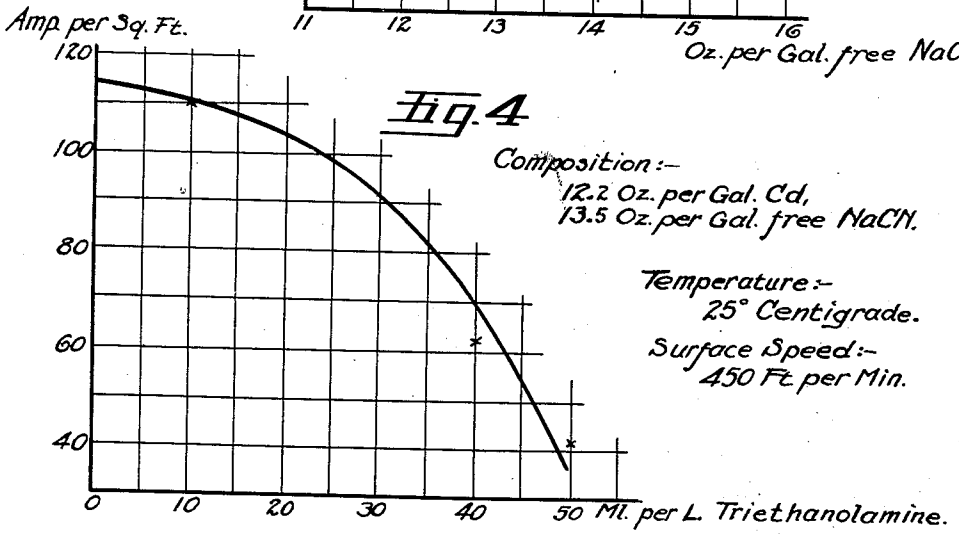


Fig. 4

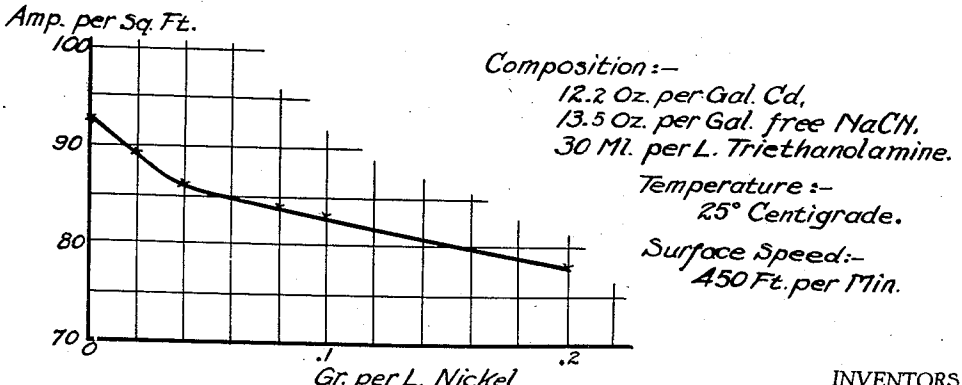


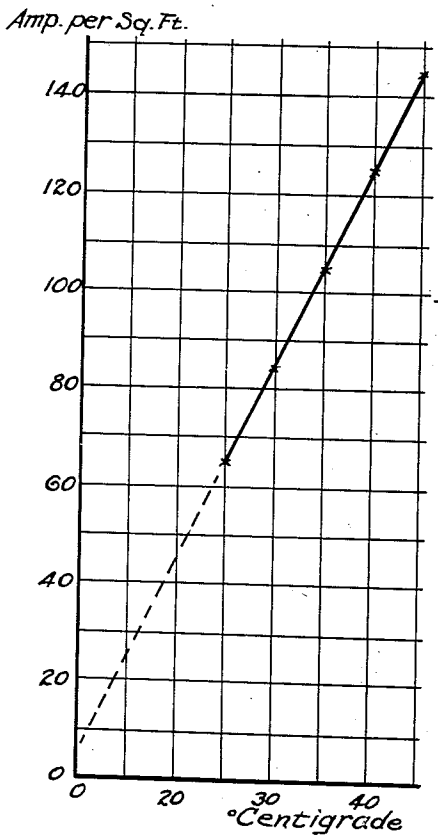
Fig. 5

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DUCTILE CADMIUM COATING

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Composition :-
12.2 Oz. per Gal. Cd,
13.5 Oz. per Gal. free NaCN,
40 Ml. per L. Triethanolamine,
.06 Gr. per L. Nickel.

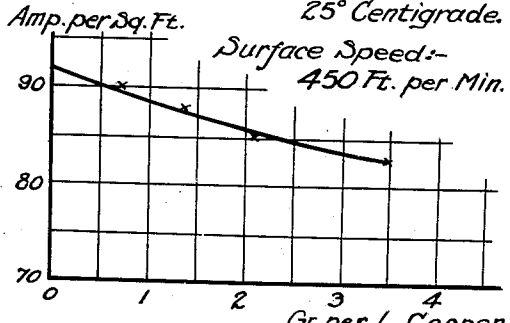
Surface Speed :-
450 Ft. per Min.

Fig. 7

Fig. 6

Composition :-
12.2 Oz. per Gal. Cd,
13.5 Oz. per Gal. free NaCN,
30 Ml. per L. Triethanolamine.

Temperature :-
25° Centigrade.



Surface Speed :-
450 Ft. per Min.

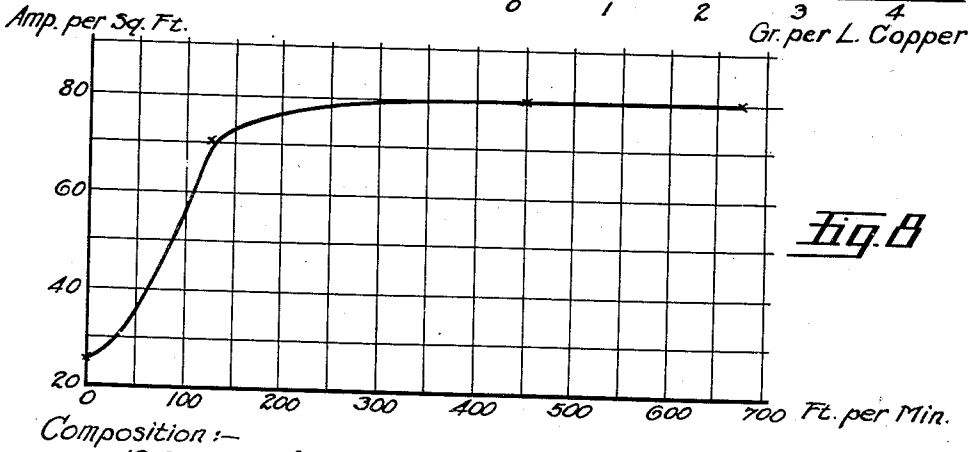


Fig. 8

Composition :-
12 Oz. per Gal. Cd,
14 Oz. per Gal. free NaCN,
30 Ml. per L. Triethanolamine,
2.2 Gr. per L. Copper.

Temperature :-
25° Centigrade.

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2,107,806

UNITED STATES PATENT OFFICE

2,107,806

DUCTILE CADMIUM COATING

Karl Gustaf Soderberg and Henry Brown, Detroit, Mich., assignors to Udylite Company, Detroit, Mich., a corporation of Indiana

Application June 3, 1936, Serial No. 83,347

21 Claims. (Cl. 204—1)

This invention relates to the production of cadmium coatings with certain desirable mechancial properties, especially high ductility.

It is an object of this invention to produce a cadmium deposit having high ductility when the deposit is relatively light, for example, having thickness from .0025 mm. upward to .025 mm., as well as when the coating is relatively heavy, for example, having a thickness of .025 mm. upward to .75 mm., or even more.

It is an object of this invention to produce cadmium coatings which are highly ductile from a cadmium plating bath without requiring critical control of the addition agents used therein.

This invention also contemplates production of a highly ductile cadmium coating by electrodeposition wherein the current control is made relatively easy for the average plater regardless of variations in the composition of the various baths which he may use from time to time.

In the drawings:

Fig. 1 is a vertical sectional view showing a plating apparatus suitable for use in practicing the herein described method of plating.

Figs. 2 through 8 are graphs showing the relation between the current density and the various other factors which must be controlled in the agitated plating process.

Fig. 9 is a section along the line 9—9 of Fig. 1.

Heretofore cadmium has been electrodeposited mainly for rust resistance and lustrous appearance to thicknesses varying between .0025 mm., and at the most, .025 mm. The high lustre has been obtained through the use of very active addition agents which cause extreme grain refinement and thereby a high degree of hardness, coupled with definite brittleness.

Occasionally cadmium plate has been applied for mechanical purposes, for example, on cheap ball bearings to facilitate wearing in, and on worm gears and ball joints to lessen friction. This has been accomplished by the use of very low concentration of the usual addition agents. However, there has always been a tendency for small particles of the plate to become detached and pile up in unwanted places when the plated article is used, decreasing the efficiency of the device and thereby that of the treatment. This tendency has increased with increasing thickness of the coating.

The relatively high degree of brittleness of the ordinary cadmium coatings has also been demonstrated on forming of plated sheet or strip metal by the cracking of even relatively thin coatings on sharp bends.

The use of very low concentrations of ordinary addition agents is not satisfactory because they are rather critical. One easily gets too much or too little addition agent in the bath, the former causing brittleness, the latter insufficient grain refinement.

These difficulties are particularly noticeable when relatively heavy coatings are applied.

Our invention has made it possible to produce coatings of such a high degree of ductility that sheet steel coated with more than .75 mm. thick plate can be bent repeatedly at 180° angle without any evidence of cracking of the coating.

This result has been accomplished by the use of new addition agents and by means of control of pertinent factors.

These addition agents are of two types, namely, the hydroxyaliphatic amines,

$$(OH—R)_{1-3}—N(H)_{2-0},$$

and the ether derivatives of mono-alkylene glycols, $OH—C_nH_{2n}—OR$, of dialkylene glycols, $OH—C_nH_{2n}—O—C_mH_{2m}—OR$, etc.

Examples of the first type are mono-, di- and tri-ethanol (propanol, -butanol,- etc.) amines. It should be noted that the ordinary ethyleneamines without the hydroxy-group, for example, ethylene-di-amine and diethylene-tri-amine, do not produce the desired results.

Examples of the second type are ethyleneglycol-mono-ethyl (propyl-butyl-etc.)-ether, diethylene-glycol-mono-ethyl (propyl-butyl, etc.)-ether, etc. To this type belong also the aromatic derivatives of the aliphatic ethers, for example, diethylene glycol monobenzyl ether.

A series of still plating tests in solutions containing 45 g/l of cadmium showned that tripropanolamine, $N(C_3H_6OH)_3$ was about 5 times, propanolamine $H_2N—C_3H_6OH$ about .6 times as effective as triethanolamine $N(C_2H_4OH)_3$ while diethanolamine $HN.(C_2H_4OH)_2$ was less than .4 times as effective.

Comparing the glycol ethers with triethanolamine, we find that diethylene glycol mono-

benzyl ether, $OH.C_2H_4.O.C_2H_4.O.CH_2.C_6H_5$, and diethylene glycol monobutyl ether,

$$OH.C_2H_4.O.C_2H_4.O.C_4H_9,$$

are about 5 times, diethylene glycol monoethyl ether, $OH.C_2H_4.O.C_2H_4.O.C_2H_5$, and monoethylene glycol monobutyl ether, $OH.C_2H_4.O.C_4H_9$, about twice as effective, while monoethylene glycol monoethyl ether $OH.C_2H_4.O.C_2H_5$, was not quite but nearly as effective as triethanolamine.

Thus the effectiveness of the organic addition agent of a given type increases both with increasing molecular weight of the substituted groups and with the number of such substituted groups.

In the following we have used the easily procurable and cheap triethanolamine but other addition agents of the two types mentioned above may be used just as well in proportionate concentrations.

Some factors must be controlled in a definite manner and are closely intra-related. These are the cadmium content, the free cyanide content, the content of certain metallic compounds, the temperature and the degree of agitation of the bath. Other factors of less importance are the concentrations of free alkali and of carbonate.

The necessity of close control increases with increasing desired thickness of the deposit.

In general, if a solution of a certain composition produces the desired plate at one combination of agitation, temperature and current density, the same solution will also produce this plate at certain other combinations of these factors. However, a solution of such a composition that it does not produce the desired plate at a certain degree of agitation by varying the temperature and the current density, will not produce results at any other degree of agitation, whatever temperature and current density is applied.

Still plating

Relatively thin coatings, up to about .25 mm. may be deposited by still plating without forced agitation. In order that a .25 mm. coating be applied, a high metal bath containing 75–97.5 g/l of cadmium is desired. A typical bath is

Cadmium	75 g/l
Free sodium cyanide	105 g/l
Triethanolamine	30 ml/l

This bath is best operated at about 2.7 amp/sq. decimeter. After about two hours plating time the edges show definite burning effect. If the plating has to be continued longer special steps have to be taken. One means well known in the art is the use of thiefs or shields which distribute the current more evenly over the surface. Another means is the addition to the bath of compounds of nickel or copper. Salts of nickel and copper were first brought over into the bath from nickel and copper strikes used for bonding purposes. Instead of an expected detrimental effect on the ductility, causing bright and hard plates as described in United States Patent 1,681,509, we found a marked decrease in the burning on the edges. This unexpected behavior is partly caused by the new types of organic addition agents employed in these baths, partly by the fact that only very small amounts of these metals were added and partly because plating was carried on below the current density range of visible gassing. The optimum concentration in the above bath is about .02 g/l nickel or 2.5 g/l copper at 2.7 amp/sq. decimeter and .06 g/l nickel at 2.15 amp/sq. decimeter, the nickel being in all cases the most satisfactory. It should be noted that lower current densities must be used when more than a trace of nickel or copper are added to the bath in order that the ductility be retained. This is in contradiction to the conditions when bright plate is desired as described in United States Patent 1,681,509, when higher current densities must be employed.

An increase of the current densities above those given above as optimum, causes excessive burning and loss of ductility. As the current densities are lowered the crystal structure of the plate gets increasingly coarser and its ductility less and less.

A higher metal content moves the plating range for ductile plate towards higher current densities. Thus while 2.7 amp/sq. decimeter is an optimum at 75 g/l cadmium, 3.0 amp/sq. decimeter are preferred at 90 g/l. A solution containing 112.5 g/l cadmium is too close to the saturation point to be practical and does not give as ductile a plate as desired.

Lower metal contents make it necessary to use lower current densities, which is economically undesirable unless very thin coatings are applied.

A higher free cyanide content than 105 g/l causes a decrease in the optimum current density, from about 2.7 amp/sq. decimeter to about 2.4 amp/sq. decimeter at 120 g/l free sodium cyanide. Lower free cyanide contents than 105 g/l tend to give coarser crystals and decrease the maximum plate thickness obtainable.

The concentration of triethanolamine is not very critical and can be varied between 20 and 40 ml/l without any material change in the plate structure.

Agitated plating

In order to deposit .50 mm. to .75 mm. thick coatings vigorous agitation must be applied.

For plating sheet steel, subsequently formed into "steel back" bearings, a set-up as shown in Fig. 1 was employed. The sheet steel is bent to a cylinder 1, with the edges welded together in a few spots. The cylinder is supported on a hard rubber plate 3 of circular shape. The plate 3 is carried by a shaft 2 and protrudes around the edges of the cylinder as at 4 to shield the lower edge of the cylinder 1. A circular steel plate 5 is also carried by shaft 2 and is secured to the cylinder 1 adjacent the top edge by means of screws 6. This steel plate is keyed to the shaft by the screw key 7. The shaft runs through bearings 8 in a portable frame 9 and is prevented from dropping through the frame by means of a bearing 10 fastened to the shaft. The shaft is driven by a motor 11 via a gearing 12. A contact brush 13 is fastened to the frame and runs on the top of the revolving steel plate 5. This brush is connected to a negative bus bar.

The whole frame with the cylinder rests on the edges of the tanks used and is moved from tank to tank for cleaning, rinsing and plating. The plating tank 14 is provided with a circular anode rod 15 on which rests the bagged cadmium anodes 16. The bags 31 are preferably of unsized, thoroughly washed cotton flannel. The anodes are preferably of the ball anode type for constant anode area. The temperature of the solution is controlled by heating means such as steam coils 17 or an electric immersion heater and by cooling means, such as cold water coils 18. Automatic controllers of ordinary design are used for regulating the temperature (not shown). The solution is preferably filtered continuously.

19 and 20 are the inlet and outlet respectively. To keep the surface of the solution clean, outlet 20 may be used as an overflow into a separate tank, from the bottom of which is the outlet into the filter pump.

The following bath has been found suitable:

Cadmium	90–97.5 g/l
Free sodium cyanide	90–112.5 g/l
Sodium hydroxide (formed on solution of cadmium oxide: $CdO+4NaCN+H_2O=Na_2Cd(CN)_4+2NaOH$)	60–75 g/l
Triethanolamine	30–40 ml/l
Nickel	.06–.08 g/l
Anhydrous sodium carbonate (formed by decomposition)	0–52.5 g/l

The optimum conditions for plating are:

Temperature	40° C.
Speed of rotation	100–150 meters per minute
Cathode current density	13–15 amp./sq. decimeter
Anode current density	4.3–5.4 amp./sq. decimeter
Continuous filtration	
Bagged anodes, preferably of the ball anode type. Bags preferably of unsized, thoroughly washed cotton flannel.	
Solution "broken in" with 40 amp. hrs./liter.	

As stated during the discussion of still plating the factors are closely intra-related. If one is changed, one or several other factors must also be changed in order that the desired plate be obtained.

The effect of changing metal content is best seen from the following table and Fig. 2 which show the variation of optimum current density with the metal content:

Free cyanide	100 g/l
Triethanolamine	40 ml/l
Nickel	.06 g/l
Temperature	40° C.
Speed of rotation	137 meters per minute

g/l cadmium	97.5	94.5	91.5	88.5	81.0
Opt. C. D., amp./sq. decimeter	14.5	14.0	13.5	12.8	10.2

It is noted that the optimum current density decreases rapidly with decreasing metal content at a constant free cyanide content. A straight line relation can be had if the free cyanide content is allowed to drop with the metal content. Its effect on the optimum current density is shown in the following table and in Fig. 3:

Cadmium content	93.5 g/l
Triethanolamine	40 ml/l
Nickel	.06 g/l
Temperature	40° C.
Speed of rotation	137 meters per minute

g/l free NaCN	90	100	112
Opt. C. D., amp./sq. decimeter	15.1	13.5	11.8

It is noted that the optimum current density increases with decreasing free cyanide content. However, the free cyanide content must not be decreased too much because then the ductile plate range of current densities becomes impractically narrow and the optimum plate structure becomes too coarse.

The effect of varying concentration of the organic addition agent on the optimum current density is shown in the following table and in Fig. 4:

Cadmium	91.5 g/l
Free sodium cyanide	100 g/l
Nickel	0 g/l
Temperature	25° C.
Speed of rotation	137 meters per minute

ml/l triethanolamine	0	10	20	30	40	50
Opt. C. D., amp/sq. decimeter	12.4	11.8	11.1	9.9	6.7	5.6

It should be noted that no triethanolamine gives very coarse crystals, making the plate entirely unsuitable. Ten ml/l does not give sufficient grain refinement. Twenty to forty ml/l produce excellent plates, but fifty ml/l causes a certain greyishness which shows up as a tendency toward pimples at high plate thicknesses.

The effect of varying nickel and copper contents on the optimum current density is as follows (see also Figs. 5 and 6):

Cadmium	91.5 g/l
Free sodium cyanide	100 g/l
Triethanolamine	30 ml/l
Temperature	25° C.
Speed of rotation	137 meters per minute

g/l nickel	0.0	.021	.042	.06	.08	.10	.20
Opt. C. D. amp/sq. decimeter	9.9	9.6	9.25	9.15	9.05	8.9	8.4
g/l copper	0.0	.7	1.4	2.1	3.5		
Opt. C. D. amp/sq. decimeter	9.9	9.7	9.5	9.15	8.9		

It is noted that increasing nickel or copper contents decrease the optimum current density, the nickel being most effective both in this respect and in respect to its ability to prevent burning on edges, thus widening the current density range. When the edges do not burn, the area stays constant and there is no need for current adjustment as the plating is continued over long periods of time.

The effect of temperature variation on the optimum current density is as follows (see also Fig. 7):

Cadmium	91.5 g/l
Free sodium cyanide	100 g/l
Triethanolamine	40 ml/l
Nickel	.06 g/l
Speed of rotation	137 meters per minute

Temperature, °C	25	30	35	40	45
Opt. C. D., amp./sq. decimeter	7.0	9.15	11.8	13.5	15.6

It is evident that the optimum current density increases linearly with the temperature within the range studied.

The effect of agitation or speed of rotation on the optimum current density is shown in the following table and in Fig. 8:

Cadmium	90 g/l
Free sodium cyanide	105 g/l
Triethanolamine	30 ml/l
Copper	2.2 g/l
Temperature	25° C.

Speed of rotation, ft./min.	0	30	60	125	450	675
Opt. C. D., amp./sq. decimeter	2.7	3.2	4.3	7.5	8.6	8.6

It is evident that the optimum current density increases very rapidly with increasing surface speed until about 45 meters per minute are reached, then more slowly to about 110 meters per minute. Higher speeds do not increase the optimum current density because the whole solu-

tion begins to move with the rotating cathode. The only value of higher speeds is increased anode corrosion and because of the increased centrifugal force a tendency towards less pimpling if the solution is not perfectly clear.

Speeds higher than 110 meters per minute may be used to increase the current density still further if the movement of the solution with the rotating cathode is prevented. This can be accomplished by bringing the edge of one or several flat sheets of non-conducting material close to the cylinder surface and holding it in one given position; two such sheets are shown at 21 in Fig. 1. It is attached to the frame 9 as at 22.

It was found that ductile, heavy deposits could not be obtained immediately from a new bath when high speed rotation was employed, but that the solution had to have been in use for some time. At 137 meters per minute about 40 amp. hrs/liter are necessary to insure removal of the brittleness.

A spectroscopic analysis showed that the cadmium oxide used for making the plating bath contained .010% lead, that the first plate obtained from this solution contained .015% lead and that the final ductile plate contained .005% lead. The indications are that the lead plates out preferentially and that ductile plates are not obtained until a considerable portion of it has been removed. This necessitates the "breaking in" of the solution by electrolysis or the use of specially purified salts.

"Breaking in" is not necessary in case of still plating, probably because the rate of diffusion of lead is too small to permit preferential plating out. With a rotating cathode fresh solution containing impurities is constantly brought up to the surface being plated.

The results given above for rotating cathode, were obtained from "broken in" solutions.

The character of the plate depends partly on the chemical composition of the bath and partly on the operating conditions. The inorganic constituents of the plating solution are determined according to standard analytical methods. Heretofore it has not been possible to analyze cadmium cyanide plating solutions for the organic addition agent. The hydroxyaliphatic amines, however, are simple enough compounds and can be determined because they combine with copper ions to give a deeply blue colored solution. The method used involves removal of the cyanide by means of formaldehyde or hydrogen peroxide, addition of a known amount of cupric ion, and titration with triethanolamine until the intensity of the blue color is twice that of the original when viewed through a colorimeter. This differential titration of the same solution removes the effect of any ammonia present which also gives deeply blue colored solutions with copper salts.

It has been shown previously that the current density which should be employed varies with a number of factors. If it is too low, coarse, angular, well defined crystals are formed and the plate is weak. If it is too high, uniform, closely spaced pimpling appears and the plate cracks on bending. In between is a range of current densities within which the two bad effects already described disappear and plates with maximum ductility are obtained. This plate shows relatively small inter-meshed crystals, and a few sporadic pimples which, unlike "dirt pimples" caused by incomplete filtering or absence of anode bags, cannot be torn out of the plate but can be rolled flat or cut off even with the surface.

The above mentioned low and high current density structures can be seen with the naked eye if the plates are heavy enough. Thin plates show the same tendencies and may be examined under the microscope.

The microscope may also be used to ascertain whether the solution has been "broken in" completely or not. If it has not, one finds a powdery-crystalline, talcum like sheen on the crystals, which cannot be seen with the naked eye except as a certain greyishness.

The optimum current density is just below that which causes visible gas evolution. If the exact analysis of the bath is not known, one may utilize this fact in plating. In starting plating with rotating cathode one may therefore begin with a current density definitely below the value expected from the tables, then raise the current slowly until the solution turns slightly cloudy from evolved gas bubbles, and finally drop the current about 3% of its maximum value to get the optimum current density. The upper limit is about 2½% higher than the optimum, the lower limit about 2½% lower.

In the case of still plating the protruding edges should be watched for gas evolution and the current adjusted to slightly below the current density at which the first bubbles are formed.

We claim:

1. A cadmium plating bath for plating a ductile deposit of cadmium comprising a compound of cadmium, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of the hydroxyaliphatic amines and the ether derivatives of alkylene glycols.

2. A cadmium plating bath for plating a ductile deposit of cadmium comprising a cadmium compound, a cyanide in sufficient quantity to have free cyanide present in the solution, and tri-ethanol amine as an addition agent in amounts ranging from 20 to 40 milliliters per liter of solution.

3. A cadmium plating bath for plating a ductile deposit of cadmium comprising a compound of cadmium, a cyanide in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of the hydroxyaliphatic amines and the ether derivatives of alkylene glycols, and small amounts of a metal from the group consisting of copper and nickel.

4. A cadmium plating bath for plating a ductile deposit of cadmium comprising a cadmium compound, a cyanide in sufficient quantity to have free cyanide present in the solution, and tri-ethanol amine as an addition agent in amounts ranging from 20 to 40 milliliters per liter of solution, and small amounts of a metal from the group consisting of copper and nickel.

5. A cadmium plating bath for plating a ductile deposit of cadmium comprising a compound of cadmium, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of the hydroxyalifatic amines and the ether derivatives of alkylene glycols, and a metal from the group consisting of copper and nickel in amounts of from .7 to 3.5 grams per liter and .021 to .20 grams per liter respectively.

6. A cadmium plating bath for plating a ductile deposit of cadmium comprising a cadmium compound, a cyanide compound in sufficient

quantity to have free cyanide present in the solution, and tri-ethanol amine as an addition agent in amounts ranging from 20 to 40 milliliters per liter of solution, and a metal from the group consisting of copper and nickel in amounts of from .7 to 3.5 grams per liter and .021 to .20 grams per liter respectively.

7. A method for producing a ductile coating of cadmium comprising electrodepositing the cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and a small amount of addition agent in the form of a compound from the group consisting of hydroxyaliphatic amines and the ether derivatives of alkylene glycols, and maintaining the current density at the cathode below the range of visible gassing.

8. A method for producing a ductile coating of cadmium comprising electrodepositing the cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and a small amount of addition agent in the form of a compound from the group consisting of hydroxyaliphatic amines and the ether derivatives of alkylene glycols, and a small predetermined amount of a metal from the group consisting of copper and nickel, and maintaining the current density at the cathode below the range of visible gassing.

9. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols and agitating the bath during the plating operation.

10. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols and maintaining the cadmium concentration from 75 to 105 grams per liter.

11. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols, agitating the bath during the plating operation, and maintaining the cadmium concentration from 75 to 105 grams per liter.

12. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols, and maintaining the free sodium cyanide concentration from 90 to 112 grams per liter.

13. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols, agitating the bath during the plating and maintaining the free sodium cyanide concentration from 90 to 112 grams per liter.

14. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols, and maintaining the temperature from 25° to 45° C.

15. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols, agitating the bath during the plating, and maintaining the temperature from 25° to 45° C.

16. The method of producing a ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, a metal from the group consisting of copper and nickel in amounts of from .7 to 3.5 grams per liter and .021 to .20 grams per liter respectively, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of alkylene glycols and agitating the bath during the plating.

17. The method of producing a highly ductile cadmium coating comprising the steps of electrodepositing cadmium from a bath comprising a cadmium compound, a cyanide compound in sufficient quantity to have free cyanide present in the solution, and an addition agent from the group consisting of hydroxyaliphatic amines and the ether derivatives of the alkylene glycols and agitating the bath during the plating by rotating the cathode at a speed ranging from 0 to 210 meters per minute.

18. The method of producing highly ductile cadmium coatings comprising plating the cadmium from a bath comprising from 75 to 105 grams per liter of solution of cadmium, 90 to 112 grams per liter of solution of free sodium cyanide, 20 to 40 milliliters per liter of tri-ethanol amine, a small predetermined amount of a metal from the group consisting of copper and nickel and maintaining the bath at a given temperature $\pm 1\frac{1}{2}$° C. between 25° and 45° C., rotating the cathode at a speed ranging between 0 and 210 meters per minute and maintaining the current density at a given point $\pm 2\frac{1}{2}$% between 2.7 and 15.6 amperes per square decimeter of cathode area.

19. The method of producing highly ductile cadmium coatings comprising plating the cadmium from a bath comprising from 75 to 105 grams per liter of solution of cadmium, 90 to 112 grams per liter of solution of free sodium cyanide, 20 to 40 milliliters per liter of tri-ethanol amine, a small predetermined amount of a metal from the group consisting of copper and nickel and maintaining the bath at a given temperature $\pm 1\frac{1}{2}$° C. between 25° and 45° C., rotating the cathode at a speed ranging between 0 and 210

meters per minute and maintaining the current density at a given point ±2½% between 2.7 and 15.6 amperes per square decimeter of cathode area, and for any given optimum value for any one of the above variable factors coordinating and controlling each of the remaining variable factors therewith within a certain predetermined value within its respective range to obtain optimum operating conditions for the bath.

20. A bath for plating highly ductile cadmium comprising 90 to 97.5 grams per liter cadmium, 90 to 112 grams per liter free sodium cyanide, 60 to 75 grams per liter sodium hydroxide, 30 to 40 ml/l triethanolamine, .06 to .08 g/l nickel, 0 to 52.5 grams per liter sodium carbonate.

21. The method of producing a highly ductile coating of cadmium comprising plating the cadmium from a bath having the following composition: 90 to 97.5 g/l cadmium, 90 to 112 g/l free sodium cyanide, 60 to 75 g/l sodium hydroxide, 30 to 40 ml/l triethanolamine, .06 to .08 g/l nickel, 0 to 52.5 g/l sodium carbonate, maintaining the bath at a temperature of approximately 40° C., rotating the cathode between 100 and 150 meters per minute, maintaining the cathode density between 12.9 and 15.1 amperes per square decimeter and the anode current density between 43 and 54 amperes per square decimeter.

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