The present invention is directed to a new nickel plating bath and method for electrodepositing nickel and, more particularly, to a nickel sulfamate plating bath and method for electrodepositing nickel which provides a wide variety of desirable results in regard to the electrodeposition of nickel.

In recent years, sulfamate baths have been increasingly used in the electrodeposition of nickel both for electroforming and for decorative purposes. The deposits commonly are internally stressed in tension. They are bright if the bath contains a brightening agent, but otherwise are dull.

Although the bath may be made by direct solution of pure nickel sulfamate, in practice nickel sulfamate is usually obtained as a concentrated solution and the bath is formed by diluting and then purifying the concentrated solution. This purification, which is essential in order to minimize pitting and to give deposits of the best quality, is usually carried out by electrolysing at a low current density and then by prolonged electrolysis at conventional current densities. In addition, if the concentrated solution contains organic matter, treatment with activated carbon may be required.

Commonly, a buffer, which is nearly always boric acid, and a substance which promotes anode corrosion, which is nearly always nickel chloride, are added to the diluted solution. Frequently, agents are added to prevent hydrogen pitting or to convert the internal tensile stress to compressive stress.

The concentration of the nickel sulfamate in the solution used as the electrolyte has varied in practice from 250 to 370 grams per liter (g.p.l.) as a general rule but a solution containing 450 g.p.l. nickel sulfamate has sometimes been used. It is well known that in electroplating the higher the cathode current density the greater is the speed of deposition but under given plating conditions there is a practical maximum current density above which so-called "burning" occurs. The value of this practical maximum current density depends not only on the temperature of operation but also on the rate of agitation and the composition of the anode and the cathode in the plating vat. With sulfamate baths in which the temperature of operation varies from 25°C. to 60°C. and with a solution containing 300 g.p.l. nickel sulfamate used at 60°C., a typical practical maximum current density is 200 amperes per square foot (a.s.f.). The use of a solution containing 450 g.p.l. nickel sulfamate operated at maximum current densities of 300 a.s.f. at 60°C. and 150 a.s.f. at 38°C. has been described. However, we have found that under particular conditions of agitation and electrode disposition which give satisfactory results in electroplating from a nickel sulfamate solution the maximum current density at 60°C. in a solution containing 450 g.p.l. nickel sulfamate is only 250 a.s.f. Prior experience with the plating of nickel from sulfamate solutions is discussed in publication No. 2420A of The International Nickel Company (Mond) Limited, 1964.

by R. A. F. Hammond entitled "Nickel Plating from Sulphamate Solutions.

The invention is based on the discovery that by working with more highly concentrated nickel sulfamate solutions than hitherto, it is possible to obtain various advantageous results in accordance with the current density used.

It is an object of the present invention to provide a new nickel sulfamate plating bath. It is a further object of the invention to provide a method for electrodepositing nickel employing a special plating bath containing special concentrations of nickel sulfamate.

It is a still further object of the invention to provide a method for electroforming nickel at controlled stress levels and at high rates of deposition.

It is still another object of the invention to provide a method for electrodepositing nickel at high deposition rates.

It is a still further object of the invention to provide a means for controlling the stress level in a nickel deposit while depositing nickel at a high deposition rate. Other objects and advantages of the invention will become apparent from the following description taken in conjunction with the accompanying drawing in which curve A illustrates the effect of sulfamate concentration in the bath against practical maximum cathode current density and curve B illustrates the effect of sulfamate concentration in the bath against internal stress level in the deposit at a given current density.

Broadly stated, the invention comprises a special aqueous nickel sulfamate electroplating bath of high concentration and a method for electrodepositing nickel therefrom. In accordance with the invention, the nickel sulfamate bath contains at least about 500 to about 700 g.p.l. of nickel sulfamate. The concentration of nickel sulfamate in the bath more suitably is from about 550 to about 650 g.p.l. since within this range higher deposition rates are possible and lower stress values in the deposit obtainable. Particularly advantageous results in these respects are obtained when the concentration is about 600 g.p.l. Advantageously, the bath is operated at a pH of about 4 with a pH range of 2.0 to about 5.5 being satisfactory. pH adjustment is preferably made by addition of sulfamic acid. Usual means of agitation, e.g., air agitation, may be employed. In addition to nickel sulfamate and water, the bath preferably contains a buffering agent such as boric acid in usual amounts up to saturation, e.g., from about 10 g.p.l. up to 30 or 45 g.p.l. of boric acid, and may also contain nickel chloride in amounts up to 30 g.p.l., e.g., about 3 to about 30 g.p.l. of nickel chloride (NiCl₂·6H₂O). Advantageously, about 5 g.p.l. of nickel chloride is employed as this low concentration of nickel chloride achieves the desirable effect of improving anode characteristics without materially increasing the internal stress of the resulting deposit. In operation, the bath is maintained at a temperature of about 50°C. to about 80°C. and, more advantageously, is operated in the temperature range of about 60°C. to about 70°C. It is found that unsatisfactory results from the standpoint of control of stress level of the deposit are obtained below 50°C. or, from the standpoint of thermal control of the solution, above 80°C.

The special electroplating method provided in accordance with the invention makes available great flexibility in operation, permits close control of the internal stress level and hardness in nickel electrodeposits, and enables the production of bright deposits without the addition
of special brightening agents to the bath for this purpose, all through control of the cathode current density employed. In addition, the bath provides a means for electric depositing nickel at hitherto unattainably high rates of deposit. In special cases, cathode current densities as high as 800 a.s.f. can be employed.

We have found that as the concentration of nickel sulfamate is varied the maximum current density and the internal stress in the deposit both vary in a remarkable way. This is shown by the accompanying graphical drawing. In this drawing, the abscissae are the concentration of nickel sulfamate in grams per liter, the left-hand ordinates are the practical maximum current density in amperes per square foot, and the right-hand ordinates are the stress in pounds per square inch in the deposit. The drawing shows two curves A and B both obtained at 60° C. Curve A relates to the maximum current density. Curve B relates to the stress obtained in deposits produced at a cathode current density of 50 a.s.f. It will be seen that there is a remarkable peak in curve A as the concentration of nickel sulfamate varies from 500 to 900 g.p.l. in this peak being wholly unexpected. This peak occurs in the range of 500 to 700 g.p.l. and the curve rises very sharply to 400 a.s.f. at about 600 g.p.l. and then falls again. Curve B is of similar but inverted shape showing a pronounced reduction in the stress in the concentration range used according to the invention.

The temperature of operation has a material effect on the result. If the temperature is reduced from 60° C. to 50° C., the internal stress moves rapidly in the tensile direction. Below 50° C. the tensile stress in the deposit is so high, and the maximum practical current density so reduced that the use of the solution offers no significant advantage over conventional solutions. If the solution is heated to 70° C., curve A is moved upwards and the maximum current density is raised to the remarkable level of 800 a.s.f. Increase in the temperature of the solution displaces curve B in the direction of increased compressive stress and, therefore, at any given current density the compressive stress is higher or the tensile stress lower for a higher temperature of the solution.

The invention can advantageously be employed in electroforming. It is well known that a deposit produced by electroforming should have low internal stress if it is to have the dimension stability which is required for many purposes. For example, in the preparation of the metal discs with which phonograph records are stamped, a tensile stress as high as 8,000 pounds per square inch (p.s.i.) is tolerated but zero stress would, in fact, be much preferred. For some other purposes, compressive internal stress is actually desirable. Working at 60° C. and at 600 g.p.l., an electrodeposited having an internal tensile stress of 8000 p.s.i. can be produced with a current density of about 230 a.s.f.; a deposit having zero internal stress can be produced with a current density of about 170 a.s.f.; and a deposit having a compressive internal stress of 14,000 p.s.i. can be produced with a current density of 50 a.s.f. without the use of addition agents. When a low current density, such as 50 a.s.f., is used, and the electrolyte contains no addition agents, the deposit is highly stressed in compression with the advantage that the resistance to fatigue of components plated with such a deposit is increased. If the temperature is increased to 70° C. at the same concentration, deposits of substantially zero internal stress may be obtained with current densities as high as 300 a.s.f. It is possible to effect high speed nickel plating with a current density as high as 800 a.s.f. for such purposes as the replacement of worn surfaces by electroplating in which an internal tensile stress in the deposit as high as 14,000 p.s.i. is acceptable.

In operation with baths containing about 500 to about 700 g.p.l. of nickel sulfamate and containing about 550 to about 650 g.p.l. of nickel sulfamate in accordance with the invention control of internal stress level in the deposits is achieved by correlating cathode current density and bath temperature without the use of a stress-reducing agent in the bath as set forth in the following table:

<table>
<thead>
<tr>
<th>Bath Temperature, °C</th>
<th>Minus 2,000 to plus 8,000, p.s.i.</th>
<th>Minus 1,000 to plus 6,000, p.s.i.</th>
<th>Minus 1,000 to plus 1,000, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>100 to 125</td>
<td>110 to 120</td>
<td>110 to 125</td>
</tr>
<tr>
<td>60</td>
<td>150 to 230</td>
<td>160 to 230</td>
<td>160 to 230</td>
</tr>
<tr>
<td>70</td>
<td>200 to 330</td>
<td>210 to 360</td>
<td>210 to 360</td>
</tr>
</tbody>
</table>

The internal stress levels obtained with higher current densities than those shown in the foregoing table are higher than those shown. Thus, at 55° C. internal stress levels up to about 18,000 p.s.i. tensile are obtained at current densities up to 250 a.s.f.; at 60° C. internal stress levels up to about 22,000 p.s.i. tensile are obtained at current densities up to 400 a.s.f.; at 65° C. internal stress levels up to about 18,000 p.s.i. tensile are obtained at current densities up to 600 a.s.f.; and at 70° C. internal stress levels up to about 12,000 p.s.i. tensile are obtained at current densities up to 800 a.s.f. Conversely, current densities lower than the minima given in the table at the given temperatures give lower, i.e., more strongly compressive, internal stresses than 2,000 p.s.i. compressive stress.

The deposits produced when electroforming as described hereinbefore are dull. However, if a conventional current density is used, that is to say, a cathode current density not exceeding 70 a.s.f., a bright deposit can be obtained without any brightening agent at temperatures from 55 to 70° C. This again is extremely surprising. This bright deposit has the advantage of good ductility, the percentage elongation necessary to cause cracking in a deposit applied to a ductile metal being 12%. If a high current density is used, e.g. 350 a.s.f., with a brightening agent, bright deposits can be obtained extremely quickly at a temperature from 55 to 75° C. These deposits are moderately internally stressed but this is usually unimportant when a decorative deposit is required. When a brightening agent is used any of the brightening agents commonly used in conventional bright nickel solutions based on the Watts bath, e.g., p-toluene sulfonamide, saccharin, aryl sulfonic acids, acetylene alcohols, etc., in the amounts commonly used, may be employed.

When using nickel sulfamate solutions containing from 500 to 700 g.p.l. nickel sulfamate, it is desirable to use reactive nickel anodes such as those containing a small proportion of sulfur to promote uniform corrosion.

Nickel chloride may advantageously be incorporated into the solution to promote smooth dissolution of the anode. If the anode is not reactive, the current density at the anode cannot be increased beyond about 200 a.s.f. without causing the evolution of gas even in the presence of the advantageous quantity of nickel chloride, namely, about 5 g.p.l. If it is desired to plate an article at a cathode current density of about 400 a.s.f. using an anode which does not contain sulfur, the surface area of the anode must be some two to three times greater than the cathode surface area of the article, and, if a cathode current density of 800 a.s.f. is to be used, the ratio of the surface areas will need to be as much as 5:1. It will readily be appreciated that it is difficult to arrange for the anode to be in two, three, or more cathode areas where conforming anodes are used, that is to say, anodes which take the shape of the cathode.

Provided that a sulfur-containing or other reactive anode is used, the anode current density can be increased
to 540 a.f.f. if the concentration of nickel chloride in the solution is 30 g.p.l. Although the effect of nickel chloride is to increase the stress in the deposits formed and for this reason the concentration should be kept as low as practicable, the coatings formed at the highest current densities are under considerable stress already and the increase in stress is not of such great importance.

Nickel sulfamate plating solutions provided in accordance with the invention have certain additional advantages over conventional plating solutions. In particular, the throwing power of the electrolyte is superior to that of conventional sulfamate solutions and the Watts-type solutions. A method for measuring throwing power using a Hull cell is described in the paper entitled "The Throwing Power of Nickel and Other Plating Solutions," by D. S. A. Watson, Transactions of the Institute of Metal Finishing, 1960, vol. 37, pages 28 to 39. Throwing power generally decreases as the current density is increased in nickel plating solutions. A solution according to the invention containing 600 g.p.l. nickel sulfamate and approximately 5 g.p.l. nickel chloride was compared at 60° C. with a conventional nickel sulfamate solution containing 300 g.p.l. nickel sulfamate and 5 g.p.l. nickel chloride and with a conventional Watts solution comprising nickel sulfate, nickel chloride, and boric acid. The apparatus used was a Hull cell and measurements were made with a primary current ratio of 5:1 and average current densities of 50 a.f.f. and 150 a.f.f. At the lower average current density, the throwing power of the Watts solution was 8, that of the conventional sulfamate solution was 10, and that of the solution according to the invention was 13. At the higher average current density, the comparative figures for the three solutions were 4, 7 and 8.

In addition, the conductivity of nickel sulfamate solutions containing from 500 to 700 g.p.l. nickel sulfamate is satisfactory. The conductivity of an all-chloride solution is better than the conductivity of solutions of the present invention but solutions according to the present invention have higher conductivities than either a conventional Watts solution or a conventional nickel sulfamate solution.

The hardness of the deposits obtainable varies inversely with the current density. Using nickel sulfamate solutions containing 600 g.p.l. nickel sulfamate, the hardness at 200 a.f.f. is of the order of 220 Vickers Pyramid Number (V.P.N.). At 50 to 70 a.f.f., the hardness is 300 V.P.N., but when the current density is reduced to 30 a.f.f., the hardness is 400 V.P.N. Thus, it is possible to vary the hardness of successive layers of nickel plated in the same plating bath simply by changing the current density as plating proceeds. For example, a thin, very hard layer of nickel may first be deposited upon a matrix, followed by a more substantial layer of lower hardness so as to give an electroformed product with a hard face upon removal thereof from the matrix. It is known that hydration of the nickel sulfamate should be avoided. An increase in the temperature of the solution increases the rate of hydration as do a decrease in the pH of the solution and a decrease in concentration of nickel sulfamate over the range used in the invention. The increase in rate of hydration, if the solution is kept at 70° C. as distinguished from 60° C., is quite acceptable in practice. For example, if a solution containing 600 g.p.l. nickel sulfamate and having a pH of 4 is kept at a temperature of 65° C., the rate of accumulation of ammonium ions is of the order of 1 g.p.l. per year. If a similar solution is stored at 70° C., this rate of accumulation rises to only 5 to 6 g.p.l. per year. This is produced by breakdown of only approximately one-hundredth of the original nickel sulfamate. It is possible to plate from a solution which is at a temperature as high as 80° C. but the improvement in properties obtained is largely offset by difficulties which have to be overcome in the thermal control of the solution so in practice it is advantageous to work at temperatures not exceeding about 70° C.

It is beneficial during the use of the electrolyte, for example, in electroforming, to have a current density close to the lowest current density electrolysis in a subsidiary tank through which the main electrolyte is circulated continuously. This insures the continuous removal of metallic impurities such as copper, iron and zinc which contaminate the electrolyte and impair the deposit. It will be appreciated that in common with usual types of nickel plating baths, metallic impurities such as iron, copper, zinc, lead, chromium, etc., should be controlled to low levels. Thus, iron should not exceed about 0.2 g.p.l., copper and zinc should not exceed about 0.01 g.p.l. each, lead should not exceed about 0.002 g.p.l., and chromium should not exceed about 0.02 g.p.l. The foregoing impurities all have deleterious effects upon nickel electro deposits produced from nickel plating baths containing the same as is discussed, for example, at page 35 in the handbook "Practical Nickel Plating," second edition, 1959, published by The International Nickel Company, Inc.

It is to be understood that in converting "nickel sulfamate," as the term is employed herein, to the equivalent nickel concentration in the bath, the conversion factor 5.503 is to be employed. Thus, a nickel sulfamate concentration of 600 g.p.l. corresponds to an equivalent nickel concentration of 109 g.p.l. It is also to be understood that the cathode current efficiency obtained in accordance with the invention is very high, i.e., on the order of 100%. This factor enables efficient use of the high plating currents contemplated in accordance with the invention. It is further to be understood that cathode materials plated in accordance with the invention can take any of the usual forms, e.g., flat and/or curved surfaces and the like, without any impairment in results attributable to cathode shape.

The high operating cathode current densities made possible in accordance with the invention provide the very practical advantage that electroforms and other types of nickel platings can be produced in very short times. Thus, for example, nickel electroforms, etc., can be produced according to the invention in an equivalent or shorter time than that required to produce similar electrodeposited objects in other metals such as copper.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. The method for electrodepositing nickel which comprises passing a current at a cathode current density up to 800 amperes per square foot through an aqueous acid bath consisting essentially of at least about 500 and up to about 700 grams per liter of nickel sulfamate from an anode to a cathode immersed therein while maintaining the bath pH between about 2.0 and about 5.5, and while maintaining the bath temperature between about 50° C. and about 80° C.

2. The method for electrodepositing nickel at a controlled internal stress level between about 2,000 pounds per square inch compressive and about 8,000 pounds per square inch tensile which comprises passing a current from an anode to a cathode immersed in an aqueous acid bath having a pH of about 2.0 to 5.5 and consisting essentially of at least about 500 and up to about 650 grams per liter of nickel sulfamate, a buffering amount up to a saturation of boric acid, and up to about 30 grams per liter of nickel chloride, and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C. the current density is about 100 to
3,399,792

175 amperes per square foot, at 60° C, the current density is about 150 to about 230 amperes per square foot, at 65° C the current density is about 200 to about 330 amperes per square foot, and at 70° C, the current density is about 250 to about 450 amperes per square foot.

3. The method for electrodepositing nickel at a controlled internal stress level between about 1,000 pounds per square inch tensile which comprises passing a current from an anode to a cathode immersed in an aqueous acid bath consisting essentially of about 600 grams per liter of nickel sulfate and having a pH of about 2.0 and about 2.5 to about 650 amperes per square foot, and about 600 amperes per square foot, and at 65° C, the current density is about 210 to about 265 amperes per square foot, and at 70° C, the current density is about 260 to about 340 amperes per square foot.

4. The method for electrodepositing nickel at a controlled internal stress level between about 1,000 pounds per square inch tensile which comprises passing a current from an anode to a cathode immersed in an aqueous acid bath having a pH of about 2.0 to 5.5 and consisting essentially of at least about 650 grams per liter of nickel sulfate and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the current density is about 110 to about 150 amperes per square foot, at 60° C the current density is about 160 to about 200 amperes per square foot, at 65° C, the current density is about 210 to about 265 amperes per square foot, and at 70° C, the current density is about 260 to about 340 amperes per square foot.

5. The method for electrodepositing nickel which comprises passing a deposit current through an aqueous acid bath consisting essentially of acid and having a pH of about 2.0 and about 2.5 and about 650 amperes per square foot while maintaining the bath temperature between about 55° C and about 70° C.

6. The method for electrodepositing a bright nickel deposit which comprises passing a deposit current through an aqueous acid bath consisting essentially of acid and having a pH of about 2.0 and about 2.5 and about 650 amperes per square foot while maintaining the bath temperature between about 55° C and about 70° C.

7. The method for electrodepositing a bright nickel deposit which comprises passing a deposit current through an aqueous acid bath consisting essentially of acid and having a pH of about 2.0 and about 2.5 and about 650 amperes per square foot while maintaining the bath temperature between about 55° C and about 70° C.

8. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

9. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

10. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

11. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through a bath having a pH of about 2.0 and about 2.5 and about 650 amperes per square foot while maintaining the bath temperature between about 55° C and about 70° C.

12. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

13. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

14. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

15. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

16. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

17. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.

18. The method for electroforming nickel to provide an electroformed deposit wherein the internal stress level does not exceed 1,000 pounds per square inch tensile which comprises passing a current through an electrolyte consisting essentially of acid and having a pH of about 2.0 and about 2.5 at a cathode immersed therein and controlling the cathode current density and the bath temperature such that at a bath temperature of 55° C, the cathode current density does not exceed about 125 amperes per square foot, at 60° C, the cathode current density does not exceed about 180 amperes per square foot, at 65° C, the cathode current density does not exceed about 240 amperes per square foot, and at 70° C, the cathode current density does not exceed about 300 amperes per square foot.
about 500 and up to about 700 grams per liter of nickel sulfamate, boric acid in an amount up to saturation, up to about 30 grams per liter of nickel chloride, and having a pH of about 2.0 to about 5.5.

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