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(71) Applicant: Akzo N.V.
Ijssellaan 82
NL-6800 LS Arnhem(NL)

(72) Inventor: Zuurdeeg, Eduard
Lunenburg 1
NL-6714 GL Ede(NL)

(74) Representative: Sieders, René et al,
P.O.Box 314
NL-6800 AH Arnhem(NL)

(54) **Process for depositing composite coatings containing inorganic particles from an electroplating bath.**

(57) Solid inorganic particles and metals are codeposited from electroplating baths to form a coating of a very homogeneous structure, said positively charged resin particles, which have a particle size of less than 300 μm, being kept dispersed in said baths in the presence of a cationic fluorocarbon surfactant in at least the same weight ratio to the particles in the bath liquid as in an 0,005 N KNO_3-solution in which the particles assume a zeta-potential of at least +40 mV with the exclusive use of said cationic fluorocarbon compound.

Croydon Printing Company Ltd.

Akzo N.V., Arnhem. AKU 1774 R

Process for depositing composite coatings containing inorganic particles from an electroplating bath.

The invention relates to a process for the codeposition from an electroplating bath of a metal and solid inorganic particles on an object acting as cathode, which particles are kept suspended in the bath liquid in the presence of a surfactant and have an average size of less than 300 µm and are used in a concentration of 10 to 150 grammes per litre of bath liquid, and relates to objects entirely or partially provided with a coating thus deposited.

A process of the type indicated above is described in the United States Patent Specification 3 891 542. From a bath nickel and silicium carbide particles are codeposited electrolytically on an object which serves as cathode. The silicium carbide particles are kept suspended in the bath with the aid of a surfactant.Mention is made, inter alia, of sodium lauryl sulphate.

A disadvantage to the known process is that only a low percentage of particles can be incorporated into the composite layers. Mention is made of a weight percentage of silicium carbide of 3 to 5%. This percentage can only be obtained at a relatively high concentration (90 to 150 grammes per litre) of silicium carbide particles in the bath liquid. Other conditions are an exceptionally high electrolyte concentration and very vigorous agitation of the bath liquid. The latter requirement serves to inhibit sedimentation of the suspension and to obtain a sufficiently homogeneous distribution of the particles in the coating.

The present invention provides a process which makes it possible to incorporate far higher percentages of solid particles into the coatings with the use of an electroplating bath having a far lower concentration of solid particles and electrolyte and far less vigorous agitation of the bath.

The invention consists in that in a process of the known type indicated above use is made of a surfactant in the form of a cationic fluorocarbon compound in at least the same weight ratio to the particles in the bath liquid as in an 0,005 N KNO_3-solution in which the particles assume a zeta-potential of at least +40 mV with the exclusive use of said cationic fluorocarbon compound . It should be added that the use of a cationic compound for the codeposition from an electroplating bath of a metal and solid inorganic particles on an object acting as cathode has been proposed before in the United States Patent Specification 3 844 910. An amino-organosilicium compound, for instance gamma-propyltriethoxysilane is employed then to promote the incorporation into a matrix of metal of non-metallic particles such as silicium carbide. Although the results obtained with that process are better than those of the previous processes, for a great number of uses the percentage of particles incorporated is still insufficient.

Moreover, in the case of a particle size of over 10 microns the amount of non-metallic particles that can be incorporated in that way has been found to decrease with increasing average particle size.

The use of a cationic surfactant in the incorporation of solid inorganic particles into a matrix of metal also is mentioned in British Patent Specification 1 070 343. The amount of cationic surfactant employed, viz. cetyltrimethylammonium bromide, is only 10 mg per 25 grammes of particles and is insufficient to cause the particles to assume a zeta-potential of at least +40 mV in an 0,005 N KNO_3-solution. Moreover, the surfactant then employed is of the hydrocarbon type, which has a very unfavourable influence on the quality of the electrodeposited coating (ductility).

In the Japanese Patent Specification 50-45735 use is made of a surfactant of the fluorocarbon type for the codeposition from an electroplating bath of gold and abrasion-resistant non-metallic particles on an object acting as cathode. In the example given in it the incorporation of titanium nitride (Ti N) is carried out with the use of 3 g of surfactant of the fluorocarbon type per 20 g of particles. As the particles used then are very small, viz. 0,05 μm, so that the specific surface area is very large, said amount of surfactant will not be sufficient to obtain a zeta-potential in an 0,005 KNO_3-solution of at least +40 mV. Moreover, nothing is said in this patent specification about the charge of the fluorocarbon surfactant used in the example.

Finally, mention should still be made of the United States Patent Specification 3 787 294. Use is made in it of a cationic surfactant of the fluorocarbon type for the codeposition from an electroplating bath of a metal and graphite fluoride particles on an object acting as cathode. Of graphite fluoride particles, however, it is generally known that they rather resemble polyfluorocarbon particles than particles whose incorporation forms the subject of the present invention. Said United States Patent Specification can therefore not be considered to contain a general teaching with regard to the incorporation of inorganic solid particles into a metal coating.

For the determination of the surface area of the particles use is preferably made of the nitrogen adsorption method of Brunauer, Emmett and Teller (BET), which is standardized in the German Industrial Standard DIN 66132. By solid inorganic particles that can be incorporated when use is made of the present process according to the invention are to be understood here not only all particles that are of solid inorganic compounds which are inert relative to the bath conditions, such as the carbides, borides, silicides or nitrides of titanium, zirconium, wolfram, hafnium, niobium, tantalum, chromium, molybdenum, vanadium and thorium, but also particles of simple or composite metal oxides such as Al_2O_3; SiO_2; IrO_2; Cr_2O_3; ZrO_2; PbO_2; Pb_3O_4; $Al_2O_3.2TiO_2$; $BeO.SiO_2$ and ZrO_2Si. To obtain an abrasion-resistant coating especially the incorporation of SiC or B_4C particles is mentioned. Also particles of metals or metal alloys can in this way be included in composite metal coatings. Also suitable are graphite, sulphur, silicium, diamond, sulphides (such as molybdenum disulphide) and silicates (talc, mica).

The percentage of inorganic particles that may form part of composite coatings when use is made of the process according to the invention varies from a few per cent to the theoretically maximum volume percentage of around 70%. It has been found that the smaller the particles the more of them can be deposited from the same amount by weight per litre of bath liquid.

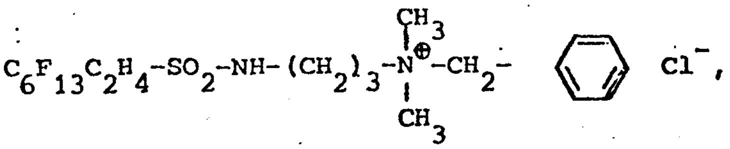
It will be clear that for the number of metals that may be used the same limitation holds as for the number that can be deposited from an electroplating bath in the known manner. As examples of these metals may be mentioned silver, iron, lead, nickel, cobalt, cadmium, copper, zinc and metallic alloys such as bronze, brass and the like.

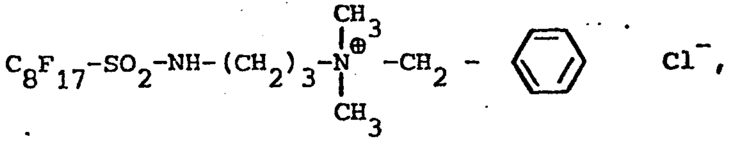
In addition to solid inorganic particles the electroplating baths used in the process according to the invention may contain particles of some other inorganic or organic material. As an example thereof may be mentioned a combination of SiC, MoS_2 and Pb-oxide + PTFE. Of particular importance in this connection are resinous particles of, inter alia, polyfluorocarbon compounds, polyvinyl chloride, polyvinylidene chloride, polyolefins, polyesters, polystyrene, polyacrylates, polyamides, polyimides, aromatic polyamides and polyurethanes. If use is made of such combination of different particles it is advisable as much as possible to choose the same particle size.

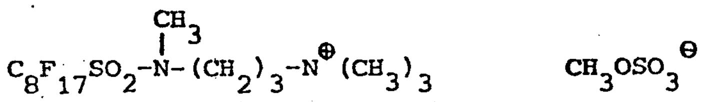
The preparation of the dispersions to be employed in the present process may be carried out in any convenient manner. It may be effected by adding the calculated amount of cationic surfactant to the electroplating bath in which the envisaged particles have been taken up or, as is preferred, first adding the wetting agent to a very strongly agitated, concentrated suspension of the particles to be occluded and subsequently adding the resulting suspension to the electroplating bath.

Particularly in the simultaneous incorporation of resinous particles it is very much advisable that the various dispersions should be prepared separately prior to their being added to the electroplating bath.

In the process according to the invention use should be made of cationic surface active fluorocarbon compounds. The structural formulae of some of these compounds are as follows:







$$C_8F_{17}SO_2-\overset{CH_3}{\overset{|}{N}}-(CH_2)_3-N^{\oplus}(CH_3)_3 \qquad CH_3OSO_3^{\ominus}$$

$C_8F_{17}-SO_2-NH-(CH_2)_3-N^{\oplus}(CH_3)_3 \qquad I^{\ominus}$

Of the above compounds the last-mentioned one is to be preferred in that it is a surfactant that gives the most favourable results. In view of the possibility of electrochemical oxidation and precipitation it is preferred that the anion of said last-mentioned compound be replaced with a Cl^- or SO_4^{2-} ion. Under some circumstances it may be desirable for the electroplating bath also to contain a stress reducing agent, such as p-toluene sulphonamide or saccharin.

The invention will be further described in the following examples, which are all directed to the codeposition from an electroplating bath of a metal and solid inorganic particles of various chemical compositions and particle sizes. First of all a description will be given of the general conditions used in the examples, after which the results of the experiments will be summarized in a number of tables.

The experiments according to the process of the invention were carried out with the use of a cationic fluorocarbon-containing surfactant. For comparison, experiments also were carried out in the presence of a cationic surfactant not containing a fluorocarbon chain, viz. a surfactant of the hydrocarbon type.

Measurement of zeta-potential

Preparatory to the experiments first the zeta-potential of the solid inorganic particles to be incorporated by electrodeposition was measured as a function of the amount of surfactant. This was done in order to determine at what amount of surfactant the particle potential exceeded +40 mV. In the actual experiments in the electrolyte bath then a somewhat larger amount of surfactant was used than the amount thus determined. Moreover, in Example I experiments were carried out with the same surfactant in 2 concentrations that were lower than that of said determined amount. The measurement of the zeta-potential was so carried out that as far as possible the same concentrations of the solid inorganic particles in the aqueous dispersions were used as those that were to be employed in the electroplating bath.

In 350 ml-beakers a series of dispersions were prepared, one of them consisting of 12½ grammes of solid inorganic particles and 250 ml of demineralized water. The other dispersions of the series contained varying amounts of surfactant as well as 12½ g of solid inorganic particles and 250 ml of demineralized water. For each of the various kinds of particles a separate series of dispersions were prepared in this way. By "various kinds of particles" are not only to be understood here particles of different chemical compositions, but also those that only differ in particle size. The contents of the beakers were homogenized for 2 minutes with an Ultra Turrax stirrer, type T 45/N of the German firm of Janke und Kunkel A.G., operating at a speed of 10 000 revolutions per minute. Subsequently, the dispersions were allowed to stand for 15 hours to permit the air to escape. Next, the dispersions were stirred with a magnetic stirrer for about 10 minutes without air occlusion and visually inspected then for stability, flocculation symptoms and sedimentation speed. Subsequently, the dispersions were stirred with the magnetic stirrer for about 5 minutes, after which from each beaker 1 ml of the dispersion was taken, which was diluted with 50 ml of an aqueous 0,05% - solution of KNO_3 (0,005 N KNO_3-solution).

Of the dispersions thus diluted the velocity of the solid inorganic particles under the influence of an electric field was measured.

From this velocity, the electric conductivity of the dispersion and the electric field strength, the zeta-potential was calculated. For further particulars about the measurement of the zeta-potential reference is made to "Electrophoresis", Duncan J. Shaw, Academic Press, London, New York, 1969.

In the following Example I the procedure used in the experiments will be further described. The same procedure, mutatis mutandis, is used in all the other examples. Differences, if any, between the examples will appear from the respective tables. In these tables are summarized the various conditions used in the experiments and the results obtained with the experiments.

Example I

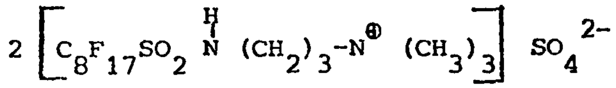
For the electrolyte bath use was made of a Watt's nickel plating bath, the solid inorganic particles of silicium carbide having being supplied by Kempten GmbH, Munich, under the name SiC 1200. They are particles having a mesh value of 1200 and an average size of about 5 µm.

A 1½ l-Watt's nickel plating bath was prepared employing the following composition ingredients:

	grammes/litre
$NiSO_4.6H_2O$	240
$NiCl_2.6H_2O$	40
H_3BO_3	40

The pH was 4,2 and the temperature 52°C.

To this bath there were added 75 grammes of SiC_{1200} and 375 mg of a cationic fluorocarbon surfactant, i.e. 5 mg of surfactant per 1 gramme of SiC. The surfactant had the following structual formula:



$$2\left[C_8F_{17}SO_2\overset{H}{N}(CH_2)_3-N^{\oplus}(CH_3)_3\right]SO_4^{2-}$$

In a 200 ml-beaker this mixture was homogenized with an Ultra Turrax stirrer of the type mentioned before at a speed of 10 000 revolutions per minute. Subsequently, the resulting dispersion was gently stirred for half an hour at a temperature of 52°C with an IKA Combimag magnetic stirrer to allow the escape of air occluded in the preceding stirring operation.

As could afterwards be established , the dispersion obtained looked moderately stable.

As cathode now a round bar of stainless steel 60 mm long and 4 mm in diameter was hung in the bath contained in the beaker. The bar had been pretreated successively by blasting with granular corundum having a mesh value of 220, rinsing, degreasing with an alkaline detergent, rinsing, activating in a boiling solution of $FeCl_3$ and again rinsing with water.

The anode hanging in the beaker consisted of a nickel plate 1 mm thick, 8 cm heigh, and 15 cm long and was so bent that it was just touching the inside wall of the beaker. The anode and the cathode were then connected to a current source supplying a direct current of 0,75 A.

So considering the cylindrical outer surface area of the cathode the current density was 10 A/dm^2. The electrodepositing lasted 15 minutes, the bath being moderately stirred to prevent sedimentation of SiC particles. Next, the cathode and the anode were removed from the beaker, rinsed with water and transferred to a beaker of the same dimensions containing a normal Watt's nickel plating bath (without SiC or surfactant). In this bath the cathode bar was subjected to a continued electroplating treatment lasting 30 minutes at a current density of 5 A/dm^2. As a result, a second, entirely nickel coating was deposited on the composite coating of nickel and silicium carbide formed in the first electroplating step.

Of the bar thus treated a 15 mm long piece was sawn off and entirely embedded in a solidifying mass. Then the integrated whole of embedding mass and bar was ground off until a semi-cylindrical part of the bar was left, the outer nickel coating serving as supporting layer.

On the fine-ground face the incorporated darker SiC particles could be very well distinguished from the lighter nickel.

The uniformity of distribution of the SiC particles in the nickel could therefore be very well determined visually. The volume percentage of incorporated SiC particles was determined with a Zeiss microvideomat

The experiment was carried out at 3 different concentrations of surfactant, based on the amount by weight of SiC particles:

a. 5 mg of surfactant per gramme of SiC
b. 10mg of surfactant per gramme of SiC
c. 20mg of surfactant per gramme of SiC

The results of the experiment are summarized in Table 1, which also gives the above-mentioned experimental conditions.

By the term "zeta-potential without surfactant" used in this table and also in other tables is meant the zeta-potential which was measured with the dispersion which exclusively contained the respective inorganic particles and demineralized water.

As is shown by Table 1, the use of respectively 5 and 10 mg of surfactant per gramme of particles resulted in incorporating only little SiC, which was moreover inhomogeneously distributed in the nickel. The zeta-potentials in the corresponding 0,005 N KNO_3-solutions were below +40 mV and were -25 and +12mV, respectively. It was also found that during the dispersing of the electrolyte, the particles and the surfactant, using 5 and 10 mg of surfactant per gramme of SiC, respectively, a flocculent to very flocculent mixture was formed.

Both quantitatively and qualitatively the incorporation was considerably better when use was made of 20 mg of surfactant per gramme of particles having a zero-potential of +76 mV. The volume percentage of the incorporated SiC particles was 57, and the particles were homogeneously distributed in the nickel.

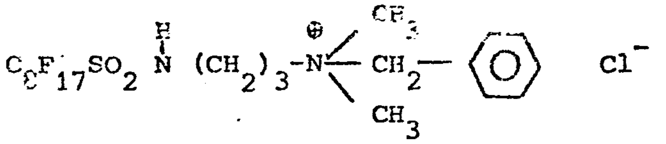
Example II

The procedure used in Example I was repeated with SiC particles having a size of about 15 µm and supplied by the Dutch firm of Norton at Rotterdam under the name SiC 500. The conditions and the results are given in Table 2.

Example III

In the experiment relating to this example the solid inorganic particles were of B_4C. Particles of this boron carbide having a particle size of about 2 µm, known under the name B_4C_{1500}, had been obtained from the German firm of Kempten GmbH, Munich.

Use was made of a nickel sulfamate bath and a different cationic fluorocarbon surfactant from the one used in the Examples I and II. The surfactant now had as structural formula



Further conditions and the results of this experiment are included in Table 3. The table shows that under the given conditions the particles were quite satisfactorily incorporated, both quantitively and qualitatively, also when use was made of boron carbide.

Example IV

In this example use was made of solid inorganic $MoSi_2$ particles supplied by the firm of Starck at West-Berlin, The bath was again a Watt's nickel plating bath and the surfactant again of the type used in the Examples I and II. Further data are mentioned in Table 4. Also in this experiment both a qualitatively and quantitavily satisfactory incorporation of particles was obtained .

Example V

The material of the solid inorganic particles in this experiment was a diamond powder supplied by the Swiss firm of Rudolf Spring A.G. under the name Diamond grade 3. Use was made of a nickel sulfamate bath and the same type of surfactant as employed in Example III. Table 5 gives further particulars about the conditions used in and the results obtained by the experiment. Considering the relatively small concentration of diamond powder (as little as 20 g/litre bath liquid) a remarkably high percentage of incorporated diamond powder was reached (28%) compared with the percentage obtained with the known electroplating process for deposition of metals and diamond powder .

Example VI

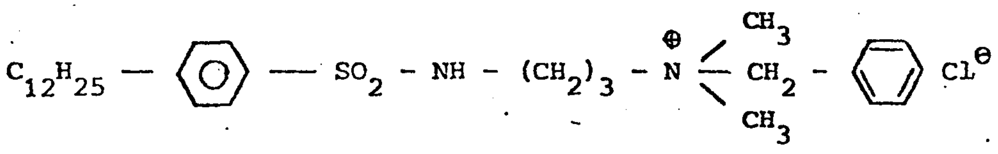
In the experiment relating to this example the solid inorganic substance consisted of chromium powder having a particle size of about 2 µm. The powder had been supplied by the American firm of Alfa Products at Danvers. The experiment was again carried out in a Watt's nickel plating bath, use being made of the same surfactant as in Example I. The conditions and the results of the experiment are given in Table 6. The composite layer contained 47 per cent by

volume of chromium powder which was homogeneously distributed in it. When this experiment was carried out in accordance with the procedure described in said British Patent Specification 1 070 343, using as surfactant n-hexadecyltrimethyl ammonium bromide (CTAB) (a non-fluorocarbon-containing surfactant) the zeta potential was found to have a value not exceeding +20 mV. The particles were inhomogeneously distributed over the surface.
The resulting coating was black and had a poor appearance.

In the following three comparative examples use was made, as in Example I, of a Watt's nickel plating bath containing dispersed silicium carbide particles referred to as SiC_{1200}. However, instead of with a cationic fluorocarbon surfactant the treatment was carried out in the presence of cationic hydrocarbon surfactants.

Example VII

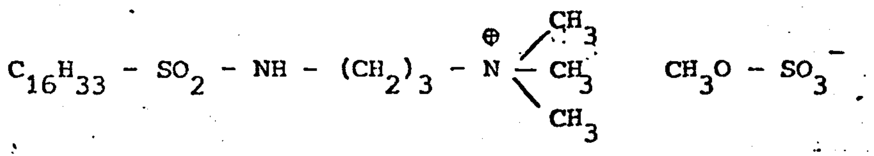
In that case the cationic hydrocarbon surfactant had the following structural formula:



The conditions and results of the experiments are shown in Table 7.

Example VIII

The cationic surfactant used here had the following structural formula:



$$\mathrm{C_{16}H_{33}-SO_2-NH-(CH_2)_3-\overset{\oplus}{N}(CH_3)_3 \qquad CH_3O-SO_3^{-}}$$

Further data are mentioned in Table 8.

Example IX

In the experiment carried out according to this example use was made of a cationic surfactant having the structural formula:

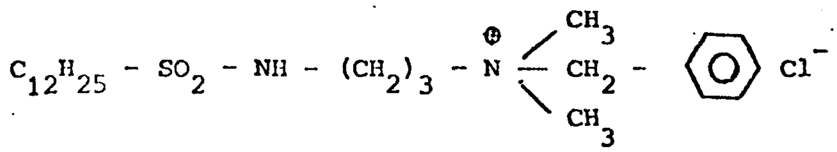


Table 9 gives further data on experimental conditions and results.

Although in all the comparative Examples VII - IX the zeta-potential can be seen to lie above the set lower limit of +40 mV, the use of a cationic surfactant which is not of the fluorocarbon type results in the incorporation of a considerably lower amount of SiC than is the case in Example I for a zero-potential of +76 mV (0, 12 and 10 per cent by volume in the Examples VII, VIII and IX, respectively, against 57 per cent by volume in Example I).

Example X

In the experiment according to this example use was made of a mixture of two inorganic substances. One substance was SiC_{1200}, as employed in Example VIII. The other substance was molybdenum disulphide having a particle size of about 25 µm. It had been obtained from the Swiss firm of Fluka A.G.
The experiment was again carried out in a Watt's nickelplating bath, use being made of the same surfactant as in Example I.
In tabel 10 the conditions used and the results obtained are summarized. The composite layer contained 27 per cent by volume of silicium carbide and 18 per cent by volume of molybdenum disulphide. Both substances were homogeneously distributed in the metal coating.

Table 1

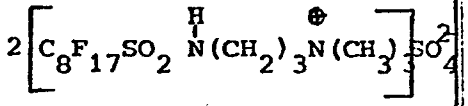
Inorganic particles	supplier	Kempten GmbH
	particle size	about 5 μm
	density	3,25 g/cm^3
	specific surface area	about 2 m^2/g
silicium-carbide ("Sic 1200")	zeta potential without surfactant	-57 mV
	zeta potential with surfactant in a concentration of	
	a. 5mg per g of particles	-25 mV
	b. 10mg per g of particles	+12 mV
	c. 20mg per g of particles	+76 mV
	content in the bath	50 g/litre
Surfactant	type	cationic, FC-type
	structure	 $2\left[C_8F_{17}SO_2\overset{H}{N}(CH_2)_3\overset{\oplus}{N}(CH_3)_3\right]SO_4^{2-}$
	content relative to the inorganic particles	a. 5 mg surf./gramme of particles
		b. 10 mg " " " "
		c. 20 " " " "
electrolyte bath	$NiSO_4 \cdot 6\ H_2O$	240 g/l
	$NiCl_2 \cdot 6\ H_2O$	40 g/l
	H_3BO_3	40 g/l
Watt's nickel plating bath	pH	4,2
	temperature	52°C
	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar, 4mm diam., 60 mm long
	current density	10 A/dm^2
	bath agitation	moderate (with magnetic stirrer)
	electroplating time	15 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring time	1 minute
	rating of mixture with:	
	a. 5 mg surf. per g of part	flocculent
	b.10 " " " " " "	very flocculent
	c.20 " " " " " "	homogeneous and stable
composite coating of nickel and SiC particles	volume percentage/distribution of incorporated particles with:	
	a. 5 mg surf. per g of part	9%/inhomogeneous
	b. 10 " " " " " "	4%/inhomogeneous
	c. 20 " " " " " "	57%/homogeneous
	coating thickness	30 μm

Table 2

Inorganic particles	supplier	Norton, Rotterdam
	particle size	about 15 µm
	density	3,25 g/cm3
	specific surface area	about 0,7 m^2/g
Silicium carbide ("SiC 500")	zeta potential without surfactant	-38 mV
	zeta potential with surfactant in a concentration of 25 mg per g of particles	+65 mV
	content in the bath	35 g/litre
surfactant	type structure	as in Table 1
	content relative to the inorganic particles	25 mg of surfactant/gramme of particles
electrolyte bath	$NiSO_4 \cdot 6\ H_2O$	240 g/l
	$NiCl_2 \cdot 6\ H_2O$	40 g/l
	H_3BO_3	40 g/l
Watt's nickel plating bath	pH	4,1
	temperature	50°C
	bath vessel	1500 ml-beaker
	anode	nickel grains in bag
	cathode	stainless steel bar 4 mm diam, 60 mm long
	current density	5 A/dm^2
	bath agitation	moderate
	electroplating time	150 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirrer time	4 minutes
composite coating of nickel and SiC particles	volume percentage / distribution of incorporated particles with 25 mg of surfactant per g of particles	40%/homogeneous
	coating thickness	about 180 µm.

Table 3

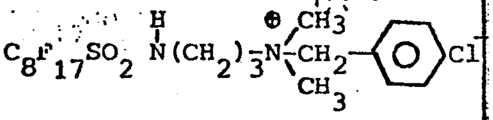
Inorganic particles	supplier	Kempten GmbH
	particle size	about 2 µm
	density	2,52 g/cm^3
	specific surface area	about 6 m^2/g
boron carbide ("B$_4$C$_{1500}$")	zeta-potential without surfactant	-50 mV
	zeta potential with surfactant in a concentration of 50 mg per gramme of particles	+72 mV
	content in the bath	30 g/l
surfactant	type	cationic FC-type
	structure	
	content relative to the inorganic particles	50 mg surf./gramme of partic
electrolyte bath	Ni(NH$_2$SO$_3$)$_2$	460 g/l
	NiCl$_2$	5 g/l
	H$_3$BO$_3$	40 g/l
nickel sulfamate bath	pH	4,1
	temperature	55°C
	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar 4 mm in diam., 60mm long
	current density	15 A/dm^2
	bath agitation	moderate (with magn. stirrer)
	electroplating time	15 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	speed of stirrer	10 000 r.p.m.
	stirring time	2 minutes
composite coating of nickel and B$_4$C particles	volume percentage/distribution of incorporated particles with 50 mg of surf. per g of particles	45%/homogeneous
	coating thickness	50 µm

Table 4

Inorganic particles	supplier	Starck, Berlin
	particle size	5 to 6 µm
	density	abt 6,2 g/cm^3
	specific surface area	abt 1,5 m^2/g
MoSi$_2$	zeta-potential with surfactant in a concentration of 30 mg per gramme of particles content in the bath	abt +60 mV
surfactant	type	as in Table 1
	structure	
	content relative to the inorganic particles	30 mg of surf./gramme of particles
electrolyte bath	$NiSO_4 \cdot 6H_2O$	240 g/l
	$NiCl_2 \cdot 6\ H_2O$	40 g/l
	H_3BO_3	40 g/l
	pH	4,1
	temperature	55°C
Watt's nickel plating bath	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar, 4 mm diam., 60 mm long
	current density	5 A/dm^2
	bath agitation	moderate (with magnetic stirrer)
	electroplating time	60 minutes
dispersing of mixture, electrolyte particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring time	2 minutes
composite coating of nickel and molybdenum silicide	volume percentage/distribution of incorporated particles with 30 mg of surfactant per g of particles	32%/homogeneous
	coating thickness	about 60 µm

Table 5

Inorganic particles Diamond grade 3	supplier	Rudolf Spring A.G.
	particle size	2 to 4 µm
	density	3,25 g/cm^3
	specific surface area	3,9 m^2/g
	zeta-potential without surfactant	-38 mV
	zeta-potential with surfactant in a concentration of 20 mg per gramme of particles	+65 mV
	content in the bath	20 g/l
surfactant	type structure	as in Table 3
	content relative to the inorganic particles	20 mg of surfactant per g of particles
electrolyte bath nickel sulfamate bath	$Ni(NH_2SO_3)_2$	460 g/l
	$NiCl_2$	5 g/l
	H_3BO_3	40 g/l
	pH	4,1
	temperature	55°C
	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar, 4 mm in diam., 60 mm long
	current density	10 A/dm^2
	bath agitation	moderate (with magnetic stirrer)
	electroplating time	15 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring time	2 minutes
composite coating of nickel and diamond powder	volume percentage/distribution of the incorporated particles with 20 mg of surfactant per g of particles	28%/homogeneous
	coating thickness	about 30 µm

Table 6

Inorganic particles	supplier	Alfa Products
	particle size	about 2 µm
	density	7,1 g/cm^3
	specific surface area	0,85 m^2/g
chromiumpowder	zeta-potential without surfactant	-35 mV
	zeta-potential with surfactant in a concentration of 25 mg per gramme of particles	+55 mV
	content in the bath	50 g/l
Surfactant	type structure	as in Table 1
	content relative to the inorganic particles	25 mg of surfactant per 1 g of particles
electrolyte bath	$NiSO_4 \cdot 6 H_2O$	240 g/l
	$NiCl_2 \cdot 6 H_2O$	40 g/l
	H_3BO_3	40 g/l
	pH	4,1
Watt's nickel plating bath	temperature	50^{o}C
	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar, 4 mm in diam, 60 mm long
	current density	5 A/dm^2
	bath agitation	moderate (with magnetic stirrer.
	electroplating time	50 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring time	1½ minutes
composite coating of nickel and chromium powder	volume percentage/distribution of incorporated particles with 25 mg of surfactant per 1 g of particles	47%/homogeneous
	coating thickness	about 52 µ

Table 2

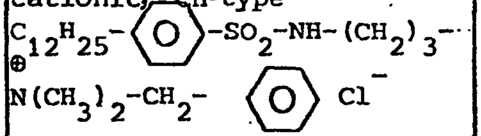
Inorganic particles	supplier	Kempten G.m.b.H.
	particle size	about 5 µm
	density	3,25 g/cm^3
	specific surface area	about 2 m^2/g
silicium carbide ("SiC 1200")	zeta-potential without surfactant	-57 mV
	zeta-potential with surfactant in a concentration of 30 mg per 1 gramme of particles	+65 mV
	content in the bath	50 g/l
Surfactant	type	cationic, CH-type
	structure	
	content relative to the inorganic partides	30 mg of surfactant per 1 g of particles
electrolyte bath	Ni $(NH_2SO_3)_2$	460 g/l
	$NiCl_2$	5 g/l
	H_3BO_3	40 g/l
	pH	4,2
Nickel sulfamate bath	temperature	55°C
	bath vessel	2000 ml-beaker
	anode	nickel plate
	cathode	stainless steel bar, 4mm in diam., 60 mm long
	current density	15 A/dm2
	bath agitation	moderate (with magnetic stirrer)
	electroplating time	15 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring time	2 minutes
	rating of mixture with 30 mg of surfactant per 1 g of particles	very flocculent
composite coating of nickel and silicium carbide	volume percentage / distribution of the incorporated particles with 30 mg of surfactant per 1 g of particles	0%
	coating thickness	about 50 µm

Table 8

Inorganic particles silicium carbide ("SiC_{1200}")	supplier	Kempten GmbH
	particle size	about 5 µm
	density	$3,25\ g/cm^3$
	specific surface area	about $2\ m^2/g$
	zeta-potential without surfactant	-57 mV
	zeta-potential with surfactant in a concentration of 30 mg per 1 gramme of particles	+ 90 mV
	content in the bath	50 g/l
Surfactant	type	cationic, CH-type
	structure	$C_{16}H_{33}-SO_2-NH-(CH_2)_3-\overset{\oplus}{N}-(CH_3)_3$ $CH_3O-SO_3^-$
	content relative to the inorganic particles	30 mg of surfactant per 1 g of particles
electrolyte bath nickel sulfamate bath	$Ni(NH_2SO_3)_2$	460 g/l
	$NiCl_2$	5 g/l
	H_3BO_3	40 g/l
	pH	4,2
	temperature	55°C
	bath vessel	2000 ml-beaker
	anode	nickel plate
	cathode	stainless steel bar, 4 mm in diam., 60mm long
	current density	$15\ A/dm^2$
	bath agitation	moderate (magnetic stirrer)
	electroplating time	2 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10,000 r.p.m.
	stirring time	2 minutes
	rating of mixture with 30 mg of surfactant per 1 gramme of particles	slightly flocculent
composite coating of nickel and silicium carbide	volume percentage/distribution of incorporated particles with 30 mg of surfactant per 1 gramme of particles	12%/inhomogeneous
	coating thickness	50 µm

Table 9

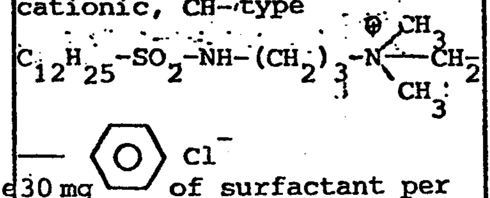
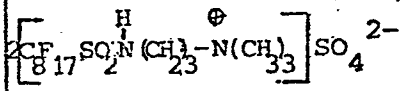
Inorganic particles	supplier	Kempten GmbH
	particle size	about 5 µm
	density	3,25 g/cm^3
	specific surface area	about 2 m^2/g
silicium carbide ("SiC$_{1200}$")	zeta-potential without surfactant	-57 mV
	zeta-potential with the surfactant in a concentration of 30 mg per 1 gramme of particles	+ 50 mV
	content in the bath	50 g/l
Surfactant	type	cationic, CH-type
	structure	
	content relative to the inorganic particles	30 mg of surfactant per 1 g of particles
electrolyte bath	$Ni(NH_2SO_3)_2$	460 g/l
	$NiCl_2$	5 g/l
	H_3BO_3	40 g/l
	pH	4,2
nickel sulfamate bath	temperature	55 °C
	bath vessel	2000 ml-beaker
	anode	nickel plate
	cathode	stainless steel bar 4 mm in diam, 60 mm long
	current density	15 A/dm^2
	bath agitation	moderate (magn. stirrer)
	electroplating time	15 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax
	stirrer speed	10 000 r.p.m.
	stirring speed	2 minutes
	rating of mixture with 30 mg of surfactant per 1 gramme of particles	slightly flocculent
composite coating of nickel and silicium carbide	volume percentage/distribution of the incorporated particles with 30 mg of surfactant per 1 g of particles	10%/inhomogeneous
	coating thickness	50 µm

Table 10

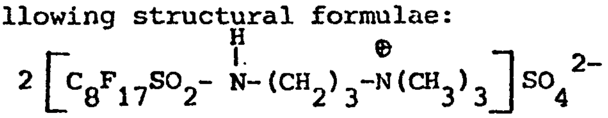
Inorganic particles	supplier of MoS_2	Fluka A.G.
	particle size	abt 25 µm
	density	4,8 g/cm^3
	specific surface area	0,5 m^2/g
silicium carbide	zeta-potential without surfactant	
	of SiC	−55 mV
	of MoS_2	not measurable (strongly hydrophobic)
as in example VIII and MoS_2	with surfactant in a concentration of	
	25 mg per g SiC	+65 mV
	25 mg per g MoS_2	+55 mV
	content in the bath	25 g/l SiC and 25 g/lMoS_2
Surfactant	type	cationic, FC-type
	structure	 $2\left[C_8F_{17}SO_2\overset{H}{N}(CH_2)_3-\overset{\oplus}{N}(CH_3)_3\right]SO_4^{2-}$
	content relative to the inorganic particles	both for SiC and MoS_2 25 mg/l
electrolyte	$NiSO_4 \cdot 6\ H_2O$	240 g/l
	$NiCl_2 \cdot 6\ H_2O$	40 g/l
	H_3BO_3	40 g/l
	pH	4,2
Watt's nickel plating bath	temperature	52°C
	bath vessel	2000 ml-beaker
	anode	bent nickel plate
	cathode	stainless steel bar, 4mm in diam. 60 mm long
	current density	7,5 A/dm^2
	bath agitation	moderate (with magnetic stirrer)
	electroplating time	30 minutes
dispersing of mixture, electrolyte, particles and surfactant	stirrer	Ultra Turrax (the two substances at once)
	stirrer speed	10 000 r.p.m.
	stirring time	2 minutes
composite coating of nickel and chromium powder	volume percentage/ distribution of incorporated particles with [illegible] 25 mg/g for the two types of particles	SiC : 27 volume % MoS_2: 18 volume % both substances were homogeneously distributed within each other
	coating thickness	about 45 µm

CLAIMS

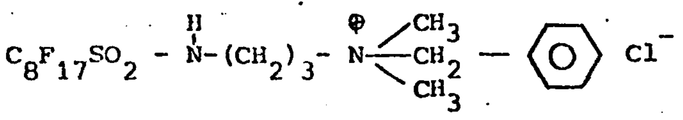
1. A process for the codeposition from an electroplating bath of a metal and solid inorganic particles on an object acting as cathode, which particles are kept suspended in the bath liquid in the presence of a surfactant and have an average size of less than 300 µm and are used in a concentration of 10 to 150 grammes per litre of bath liquid, characterized in that as surfactant there is used a cationic fluorocarbon compound in at least the same weight ratio to the particles in the bath liquid as in an 0,005 N KNO_3-solution in which the particles assume a zeta-potential of at least +40 mV with the exclusive use of said cationic fluorocarbon compound.

2. A process according to claim 1, characterized in that the amount of cationic fluorocarbon compound is so chosen that in an 0,005 N KNO_3 solution the particles assume a zeta-potential of at least + 60 mV with the exclusive use of said cationic fluorocarbon compound.

3. A process according to claim 1 or 2, characterized in that as cationic fluorocarbon compound there is used a compound having one of the following structural formulae:



$$2\left[C_8F_{17}SO_2-\overset{H}{N}-(CH_2)_3-\overset{\oplus}{N}(CH_3)_3\right]SO_4^{2-}$$



4. A process according to any one of the preceding claims, characterized in that besides solid inorganic particles simultaneously solid particles of a different kind are deposited.

5. A process according to claim 4, characterized in that the different kind of solid particles are inorganic particles, too.

6. A process according to claim 4, characterized in that the different kind of solid particles are organic particles.