WEAR-RESISTANT CAST IRON FOR SLIDING SURFACES

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Filed: Oct. 29, 1974

Appl. No.: 518,514

Foreign Application Priority Data
Nov. 1, 1973 Japan............................... 48-123204

U.S. Cl. .......................... 75/128 B; 75/123 CB; 75/128 C; 75/128 D; 75/128 F; 75/128 G; 75/128 W

Int. Cl.2........................... C22C 38/44; C22C 34/48; C22C 38/52; C22C 38/56

Field of Search.............. 75/128 D, 123 CB, 128 B, 75/128 C, 128 F, 128 G, 128 W

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ABSTRACT

A wear-resistant and self-lubricatory cast iron for use with a compositely electroplated layer of a high wear resistance in sliding contact relation. The cast iron contains, in addition to carbon, silicon, manganese and chromium, cobalt for solid solubilization with the iron matrix and provision of high heat resistance, molybdenum and niobium for formation of such specific granular carbides as composite carbides of molybdenum and carbides of niobium and providing a high wear resistance, nickel for acceleration of graphitization and even distribution of fine and dense graphite in the iron matrix, and boron for aid of such acceleration in cooperation with the molybdenum thus providing high lubricity, the remainder being iron and impurities.

1 Claim, 8 Drawing Figures
FIG. 1

FIG. 2  FIG. 3

FIG. 4

FIG. 8

MEASURING POSITIONS (8 POSITIONS MARKED WITH X) ON CIRCUMFERENCE OF CIRCLE DEFINED BY A PISTON AT TOP DEAD CENTER
FIG. 5

FIG. 6

<table>
<thead>
<tr>
<th>STATOR MATERIAL WEAR HEIGHT (μ/100km)</th>
<th>1.5</th>
<th>1.5</th>
<th>3.2</th>
<th>2.5</th>
<th>2.3</th>
<th>0.8</th>
<th>0.8</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABRASION VELOCITY (m/sec)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>STATOR MATERIAL</td>
<td>CAST IRON</td>
<td>A</td>
<td>MO SPRAY COATED</td>
<td>CAST IRON</td>
<td>Z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROUGHNESS OF COMPOSITE ELECTROPLATED SLIDING SURFACE (μ)</td>
<td>1.0</td>
<td>2.0</td>
<td>1.2</td>
<td>1.8</td>
<td>2.0</td>
<td>1.2</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

FIG. 7
WEAR-RESISTANT CAST IRON FOR SLIDING SURFACES

BACKGROUND OF THE INVENTION

The present invention relates to a metal material for use in sliding contact with a metal surface coated with a compositely electroplated layer having a coprecipitated substance protruding above the electroplated metal surface.

Cast iron has heretofore been used as a metal material for use in sliding contact with a metal surface coated with a compositely electroplated layer which has scaly graphite, granular graphite, or globular graphite distributed through coprecipitation in uniform state therein. Also, known is a metal material wherein, onto the surface of a cast iron metal, molten molybdenum is sprayed, or hard chromium or bronze is electroplated. Such materials have their own respective properties such as elastic modulus, deflection strength, hardness, impact resistance and fatigue limit stress, and considerations of such individual properties have inevitably forced one to compromise in the use thereof for one purpose, since they have not completely satisfied the requirements in use throughout their properties. In other words, when a metal material of hard quality is used to mate with an electroplated surface, the compositely electroplated surface in sliding contact therewith is liable to wear readily. When a metal of soft quality is used, the compositely electroplated surface is now relieved from such wear problem, but it is inevitable that the corresponding material of soft quality is subject to wear and/or fusion seizure due to abrasion in operation, thus resulting in abnormal wear of the material.

In view of the above stated difficulties associated with the conventional metals for application to a corresponding part of a mechanical structure which is adapted to slidably contact with a compositely electroplated surface as described above, it would be advantageous if such a metal were to be developed which could be used with freedom from any possibility of abnormal phenomena described hereinbefore. This invention is essentially directed toward meeting such requirements.

SUMMARY OF THE INVENTION

It is therefore a primary object of this invention to provide a metal material providing a surface for sliding contact with a compositely electroplated layer surface, and having a substantial hardness whereby a positive resistance against wear due to abrasion is obtained. It is another object of this invention to provide a metal material providing a porous surface which provides depressions for maintaining lubricant therein, whereby satisfactory lubrication may be assured between the sliding contact surfaces of a mechanical structure.

It is still another object of this invention to provide a metal material having a self-contained lubricant in the surface thereof, whereby scuffing and/or fusion seizure of the material due to abrasion with the associated surface are effectively prevented. It is a still further object of this invention to provide a practically suitable combination of a compositely electroplated layer with a cast metal, whereby hardness and lubricity provide an assurance of high wear resistance of the slidable contact metal members in a mechanical structure.

According to this invention, briefly summarized, there is provided an improved cast iron for use in sliding contact with a compositely electroplated layer in a mechanical structure, which contains 1.0 to 3.5 percent of total carbon, 0.5 to 3.0 percent of silicon, 0.1 to 1.5 percent of manganese, 0.1 to 2.0 percent of chromium, 1.0 to 15.0 percent of cobalt, 0.5 to 10.0 percent of molybdenum, 0.1 to 5.0 percent of nickel, 0.05 to 2.0 percent of niobium, and 0.001 to 0.1 percent of boron, the remainder being iron and impurities.

The foregoing objects, characteristics, principle, and utility of the present invention, as well as further objects and advantages thereof, will become more apparent from the following detailed description with respect to a preferred embodiment of this invention when read in conjunction with the accompanying drawings, in which like parts are designated by like reference numerals.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is an enlarged diagrammatic representation, in section, of a compositely electroplated layer adapted to serve as a sliding contact surface of a mechanical structure;

FIG. 2 is a diagrammatic front elevation showing a wear tester;

FIG. 3 is a side elevation of the wear tester shown in FIG. 2;

FIG. 4 is a graphical representation showing the results of wear tests performed by using the wear tester shown in FIGS. 2 and 3;

FIG. 5 is a side view, partly in longitudinal section, showing an ultra-high-pressure wear tester;

FIG. 6 is a graphical representation showing the results of wear tests performed by using the ultra-high-pressure wear tester shown in FIG. 5;

FIG. 7 is an enlarged diagrammatic representation, in section, of a cast iron Z according to this invention; and

FIG. 8 is a schematic view showing positions for measuring average quantity of abrasion observed in the case of Example 1.

DETAILED DESCRIPTION

There have been proposed prior arts relating to composite electroplating as typically disclosed, for instance, by a Japanese Pat. No. 280939. According to this patent, there is disclosed a method wherein there is electrolytically coprecipitated a composite film consisting of any one of metals such as nickel, chromium, copper, cadmium, and optionally selected powdered substances such as aluminum oxide, iron oxide, silicon carbide, tungsten carbide, diamond, etc. on the surface of a metal matrix, thereby providing the metal surface with extraordinary resistance against wear, heat, corrosion, etc. Among these substance applied in such composite electrolytic operation, it has been most common those skilled in the art to use nickel as a metallic component plus silicon carbide as a powdered admixture.

In this typical application, taken by way of example from among other known arts, wherein a composite film is electroplated, an electrolytic bath containing nickel sulfate, nickel chloride, boric acid and other effective admixtures is first prepared in an electrolytic cell, thereafter powdered silicon carbide is further dispersed evenly to be suspended therein. In this particular electrolytic bath, it is essential to use caution to
keep the powdered substance admixed from settling in the bath. Electrolytic nickel is used as anode and a metallic material to be coated is used as cathode. With such arrangement, electrolytic operation is performed by passing a current through the electrolytic cell and then coprecipitated on the surface of said material is powdered silicon carbide to be evenly dispersed in the electrolytically deposited layer of nickel. In this electrolytic operation, silicon carbide as a coprecipitate is of a particle size of approximately 4 μ, and the quantity of the silicon carbide to be coprecipitated in the compositionally electrolytically deposited layer is approximately 6% by weight. Silicon carbide is a material having a knoop hardness of 2480, and, therefore, a compositionally electrolytically deposited layer of high wear resistance can be produced by coprecipitating silicon carbide in a nickel matrix. In practice, such an electrolytically deposited layer may be applied to the interior wall surfaces of an internal combustion engine cylinder, the sliding contact surfaces of a machine tool, the engaging surface of a clutch plate, and the like. In such an application, it is well known to those skilled in the art to use a compositionally electrolytically deposited layer which has improved wear resistance, in the following manner.

In the case of the interior wall surface of an internal combustion engine cylinder, for instance, wherein abrasion takes place on the compositionally electrolytically deposited layer thereof under wet conditions, there is provided a sliding surface of porous character, which is available for containing a lubricant therein, whereby the lubricant may be supplied incessantly on the sliding surface of the engine cylinder, thus preventing undesired abrasion from progressing. For this purpose, such treatment as electrolytic polishing, chemical polishing, and/or mechanical polishing are applied to the compositionally electrolytically deposited layer of nickel-silicon carbide. During this polishing treatment, nickel in the compositionally electrolytically deposited surface is subject to electrolytic dissolution, chemical dissolution, or mechanical dissolution, depending on the polishing treatment referred to above.

In contrast, silicon carbide per se is not affected by such polishing treatment and so remains in the compositionally electrolytically deposited surface as it was coprecipitated originally. Consequently, silicon carbide assumes a state of protrusion from the electrolytically deposited surface, the protrusion height of such silicon carbide from above the surface of nickel matrix being of the order of 1 to 2 μ. Thus, there are formed a first sliding contact surface by silicon carbide particles per se and a second sliding contact surface by the electrolytically deposited surface of the nickel matrix, thus forming spaces or depressions available for containing the lubricant between the first and second sliding contact surfaces. The thus obtained surface having silicon carbide particles protruding above the surface of compositionally electrolytically deposited layer so as to form depressions available for containing the lubricant (hereinafter referred to as "compositionally electrolytically deposited surface") has a wear resistance superior to that obtained in the conventional compositionally electrolytically deposited layer.

In FIG. 1, there is shown an enlarged sectional view of a sliding surface obtained by the above described composite electroplating technique and comprising a first sliding contact surface 1, a second sliding contact surface 2, and silicon carbide particles 4 protruding from the surface of a nickel matrix 5, spaces or depressions for containing the lubricant being formed between the silicon carbide particles and the two sliding contact surfaces.

Also, known is the use of cast iron as a metal material for a mechanical part corresponding, in cooperative sliding contact, to the above mentioned compositionally electrolytically deposited layer surface. Cast iron has minor differences in its physical properties according to the configuration and quality of graphite precipitated in the structure thereof. However, cast iron has been widely used in such application for the following reasons.

Graphite contained in the structure of cast iron has advantages such as its ability to store the lubricant so as to prevent the interruption of the lubricant film and its own lubricity. Moreover, the depressions from which graphite has come off become available for containing the lubricant, and, also, it can quickly dissipate frictional heat by virtue of its high thermal conductivity and can fit by running-in against the contour of the electrolytically deposited member surface by virtue of its low elastic modulus.

In the abrasion phenomenon observed in mechanical members in sliding contact with each other, there are a so-called initial abrasion which occurs in the initial stage of use before the members become fitted smoothly with each other, and normal abrasion which occurs in the normal operation later than the above mentioned initial abrasion. It is known that a maximum quantity of wear is observed in such cases where the direction of movement is reversed and/or a lubricant film is interrupted. In this respect, it may be said that a material having the capability of maintaining the lubricant and thus preventing the interruption of a lubricant film can be considered to be a material of good wear resistance.

When the composite electrolytically deposited hereinbefore is applied to the cylinder interior wall surfaces of an internal combustion engine, it is required that piston rings be set in cooperative sliding contact with the above mentioned cylinder interior wall be of a metal material having wear resistance as high as that of the compositionally electrolytically deposited layer. Among cast iron materials for piston rings, cast iron wherein there are distributed much steadite of hard quality by increasing phosphorous in a pearlite matrix, and, further, graphite globules are evenly distributed has advantages in wear resistance, heat resistance, and strength.

In the case where the above mentioned compositionally electrolytically deposited layer is caused to slide on the surface of a cast iron material, the surface of a cast iron material is subjected to scuffing and subsequent wear due to scratching by the hard silicon carbide particles protruding above the compositionally electrolytically deposited layer surface of the complementary member. In the interior wall of such cylinder coated with the compositionally electrolytically deposited layer, there also occurs substantial wear particularly in positions near the top and bottom dead centers of a piston, where the direction of reciprocating movement of a piston is reversed, due to the interruption of lubricant film therearound. For coping with such problems, there are such treatments as application of parkering, filling of solid lubricant, spraying of molten molybdenum, electroplating of such metals as hard chromium and copper, and electroplating of bronze onto a copper and/or a chromium plated layer, but each treatment has advantages and disadvantages, and none of these treatments has been capable of solving the problems. For instance, hard chromium plating is on one
hand selected for improving the wear resistance of such piston rings in view of the hardness thereof. On the other hand, however, there are drawbacks as such hard chromium plating is not readily run-in to fit the interior wall surface of a cylinder, or the cylinder interior wall surface is subject to substantial wear. With respect to wear occurring on the part of cast iron, one case is that wherein wear is caused by chemical components contained in the cast iron, and another is that wherein the cast iron itself wears physically. In Table 1, there are shown physical properties and chemical composition of such typical cast irons A, B, and C.

Table 1

<table>
<thead>
<tr>
<th>Classification</th>
<th>Elastic modulus (Kg/mm²)</th>
<th>Hardness</th>
<th>Chemical compositions (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron A</td>
<td>11,000</td>
<td>40</td>
<td>[C, H₄C, B]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carbon</td>
</tr>
<tr>
<td>Cast Iron B</td>
<td>17,000</td>
<td>40</td>
<td>[C, H₄C, B]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carbon</td>
</tr>
<tr>
<td>Cast Iron C</td>
<td>15,000</td>
<td>40</td>
<td>[C, H₄C, B]</td>
</tr>
</tbody>
</table>

In accordance with the present invention, there is provided a special cast iron having a high wear resistance which is adaptable as a material for cast piston rings for sliding contact with the compositely electroplated layer described hereinbefore, and which is herein referred to as "cast iron Z". The cast iron Z is processed in such an ordinary manner where a cast iron is prepared, i.e., iron oxides of several additive elements, e.g., ferro-silicon, etc., are admixed to a molten gray cast iron. This cast iron has a number of advantages such as improved hardness, heat resistance, and self-lubricity over the conventional cast irons.

Now, the wear resistance of the conventional cast irons and the cast iron Z of this invention, which are used in sliding contact with the compositely electroplated layer described hereinbefore, will be shown in comparative manner in the following examples of this invention.

**EXAMPLE 1**

This example comprises an exemplary application of these cast irons to piston rings for use in an air-cooled, two-stroke-cycle, internal combustion engine having a single cylinder for a motorcycle:

Table 2

<table>
<thead>
<tr>
<th>Classification</th>
<th>Elastic modulus (Kg/mm²)</th>
<th>Hardness</th>
<th>Chemical composition (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron Z</td>
<td>20,000</td>
<td>40</td>
<td>Co</td>
</tr>
</tbody>
</table>

Table 2 indicates certain physical properties and the chemical composition of this cast iron Z. In this cast iron, cobalt added therein contributes to the improvement of heat resistance of the cast iron by solid solubilization with the matrix of the cast iron. Furthermore, the addition of molybdenum and niobium into the cast iron results in the formation of hard carbides of specific granular shape. In connection with the improvement of self-lubricity thereof, the nickel therein serves as an accelerator for the graphitization, while the boron and molybdenum cause fine graphite particles to be distributed densely and evenly in the matrix, thus effecting such improvement. This cast iron Z has an unusually high elasticity which cannot be found in the conventional cast irons, and specific granular carbides form a first sliding surface of this cast iron, thus resulting in superior wear resistance.

In this example, the interior wall surface of the engine cylinder having a bore x stroke of 56 mm x 50 mm, and a maximum output of 10.2 HP/7,500 rpm is coated with a compositely electroplated layer of Ni-SiC
of the type described above wherein SiC protrudes 1–2 μ above the nickel. For the piston rings, those made of the conventional cast iron alone, the conventional cast iron coated with a hard chromium layer, and the cast iron Z of this invention were prepared. The bench operation tests were performed for a period corresponding to a mileage of 2,000 km on road. After the test was completed, wear at the points in the cylinder interior wall surface corresponding to the top dead center of the piston and the increase in the gaps of the piston rings were measured thereby to judge the adaptability of the piston rings of such cast iron for use with the compositely electroplated layer of the cylinder wall. The points of such measurement in the cylinder interior wall surface corresponding to the top dead center (top C.C.) of the piston were selected eight in number positioned equally spaced on the circumference of a circle defined on the engine cylinder interior wall surface, which are schematically shown in FIG. 8. The results of the measurements of the average wear at the eight positions of the cylinder wall corresponding to the top dead center of the piston and increases in the gaps of the top piston ring and the second piston ring are indicated in Table 3.

Table 3

<table>
<thead>
<tr>
<th>Ring Material</th>
<th>Average wear at eight positions, top dead center (μ)</th>
<th>Increase in Ring Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron A</td>
<td>3.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Cast iron B</td>
<td>2.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Hard chromium</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Cast iron Z</td>
<td>0</td>
<td>0.10</td>
</tr>
</tbody>
</table>

EXAMPLE 2

Wear test by Ohkoshi type wear tester:

This type of wear test is schematically shown in FIGS. 2 and 3. In performing a wear test with this wear tester, a rotor 8 of 30-mm diameter covered with a compositely electroplated layer 7 was driven in rotation so as to slidable contact a fixed stator 9 under a load. Cast irons A and Z were used as materials for the stator for the wear test. The results of the wear test were indicated in terms of the amount of wear of the stator material. The conditions and results of this wear test are indicated in Table 4 and FIG. 4, respectively. The ordinate of the graph of FIG. 4 shows the volume of material in cubic millimeters which was removed during the wear test.

Table 4

<table>
<thead>
<tr>
<th>Lubricating oil</th>
<th>Velocity of abrasion [m/sec]</th>
<th>Load (Kg/cm²)</th>
<th>Distance of abrasion [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 W 30 Engine oil</td>
<td>1.02, 4.0, 7.15</td>
<td>192</td>
<td>200</td>
</tr>
</tbody>
</table>

EXAMPLE 3

Wear test by an ultra-high pressure wear tester:

This type of wear test is schematically shown in FIG. 5. In performing a wear test with this wear tester, a disc 12 measuring 80 mm in diam. × 10 mm thick covered with a compositely electroplated layer 11 was fixed stationary under a load oppositely against a jig with four stator pieces 13 fixed rigidly thereto which was driven in rotation so as to cause the stator pieces to slidably contact the stationary disc. The reference numeral 14 designates a rotating shaft of a speed changer; 15 designates an inlet for a lubricant, and 16 indicates the direction of the lubricant under pressure. The results of this wear test were indicated in terms of roughness of a sliding surface for the compositely electroplated layer surface, while for the stator material the results were indicated in terms of height of wear loss after the performance of this test for a period corresponding to the running distance of 100 km on the road. Comparison was made on the degree of wear by applying these test pieces for stator material of the cast iron A, the cast iron A sprayed with molten molybdenum, and the cast iron Z. The conditions and results of the wear test are indicated in Table 5 and FIG. 6, respectively. The roughness of the finishing degree of the compositely electroplated layer prior to the wear test was in the range of 0.6 to 1.5 μ.

Table 5

<table>
<thead>
<tr>
<th>Method of abrasion</th>
<th>Lubricated by Mobil No. 20, oil temp. 60°C, 600 cc/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity of abrasion [m/sec]</td>
<td>3, 4, 5</td>
</tr>
<tr>
<td>Load of contact [Kg/cm²]</td>
<td>70</td>
</tr>
<tr>
<td>Distance of abrasion [km]</td>
<td>100</td>
</tr>
</tbody>
</table>

As for the physical properties required by a metal material to be applied for sliding contact with a compositely electroplated layer surface, it is essential that it should not give rise to fusion seizure with the electroplated surface, it should not scuff or scratch the electroplated surface, it should have a high wear resistance, etc. In Example 1, when the cast iron Z was used, no wear on the part of the compositely electroplated surface whatsoever was observed, and, furthermore, a slight increase in the gap of the piston rings was observed. In this respect, it can safely be said that the cast iron Z is a material suitable for the manufacture of piston rings having good wear resistance for use with a cylinder interior wall having a compositely electroplated layer.

Likewise in Example 2, it is apparent that the cast iron Z has greater wear resistance than the conventional cast irons. It was found that the cast iron of Example 3 had no scuffing which was observed in the case of the cast iron A sprayed with molten molybdenum, and also was run-in appropriately to fit the compositely electroplated surface. In each of these examples, it was observed that the cast iron Z of this invention had good compatibility in associated use with the compositely electroplated layer of hard character.

Referring now to FIG. 7, there is diagrammatically shown a section of the cast iron Z of this invention showing the structure thereof. In FIG. 7, the reference numeral 18 designates a first sliding surface, 19 a second sliding surface, 20 depressions containing the lubricant, 21 carbides of specific granular shape, 22 graphite particles, and 23 the matrix of the cast iron Z. As is apparent from FIG. 7, the hard carbides of specific granular shape 21 form the first sliding surface 18.
These specific granular carbides are of hard molybdenum and niobium. It should be noted that the above mentioned specific granular carbides 21 forming the first sliding surface 18 of the cast iron Z and the silicon carbide 4 forming the first sliding surface 1 of the composite electroplated surface of the corresponding part both have high hardnesses, and, in this respect, the cooperative use of such materials for sliding contact with each other becomes suitable for such purpose by virtue of the outstandingly high wear resistance, thus affording good durability of such complementary parts of a mechanical structure.

Furthermore, as described hereinbefore, both the cast iron Z and the composite electroplated layer have depressions 3 and 20 defined between the first and second sliding surfaces thereof, respectively, for containing the lubricant therein, thus supplying the lubricant contained therein to the sliding surfaces of the complementary parts in sliding contact with each other, and thus assuring the lubricity therebetween. Consequently, improved wear resistance of the two complementary parts is assured, and, simultaneously, quick running-in of the two is effected. Furthermore, as the cast iron Z has graphite 22 commixed therein as a self-contained lubricant, this graphite functions to prevent scuffing and/or fusion seizure of the two complementary parts. In this manner, there is now obtained an idealistic combination of metal materials for use in sliding contact which solves all problems inherent in the conventional combination of metal materials for such use.

In summary, the advantageous features attained from the use, in combination, of the cast iron Z of this invention and the composite electroplated layer are as follows:

1. By virtue of the first sliding surfaces formed by hard substances on the both the composite electroplated layer and the cast iron Z, high wear resistance is assured.

2. Because of depressions formed for containing the lubricant between the first and second sliding surfaces on both the composite electroplated layer and the cast iron Z, the lubricant is incessantly supplied to the sliding surfaces thereof, so as to assure lubrication therebetween.

3. As a result of the existence of the first and second sliding surfaces of both the composite electroplated layer and the cast iron Z, in cooperation with depressions defined between these sliding surfaces, the complementary sliding parts are assured of quick running-in.

4. By virtue of self-contained lubricant of the case iron Z, there is no risk of scuffing and/or fusion seizure of the associated surfaces of the complementary sliding parts.

What we claim is:

1. A cast iron for use in a sliding contact surface of a first mechanical part adapted to cooperatively contact in sliding motion with a composite electroplated layer wherein nickel and a silicon carbide are coprecipitated of a corresponding second mechanical part, said layer being subjected to surface treatment thereby to cause particles of said silicon carbide to protrude from above the surface of the nickel constituting a matrix in said electroplated layer, said cast iron consisting essentially of 1.0 to 3.5 percent of total carbon, 0.5 to 3.0 percent of silicon, 0.1 to 1.5 percent of manganese, 0.1 to 2.0 percent of chromium, 1.0 to 15.0 percent of cobalt, 0.5 to 10.0 percent of molybdenum, 0.1 to 5.0 percent of nickel, 0.05 to 2.0 percent of niobium, 0.001 to 0.1 percent of boron, and a remainder of iron and impurities, all percentages being by weight.

* * * *