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HIROSHI SHIMANAKA ET AL

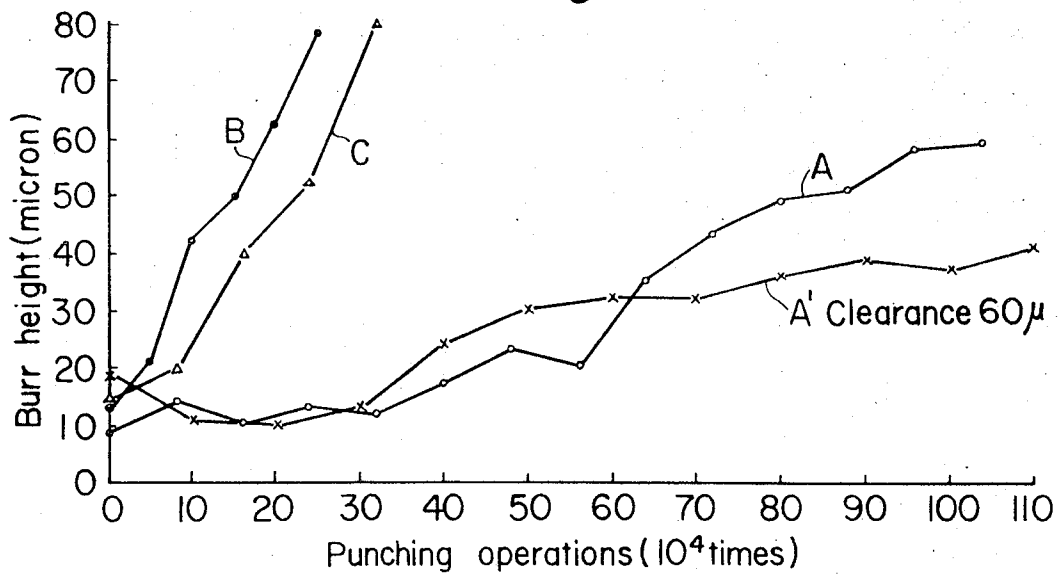
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METHOD OF IMPROVING PUNCHABILITY OF STEEL SHEETS

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4 Sheets-Sheet 1

**Fig. 1**



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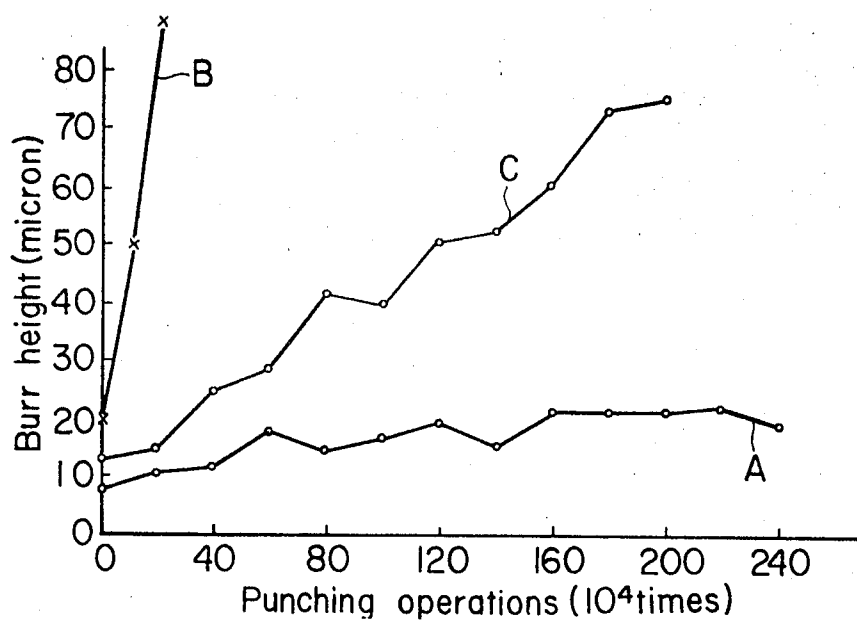
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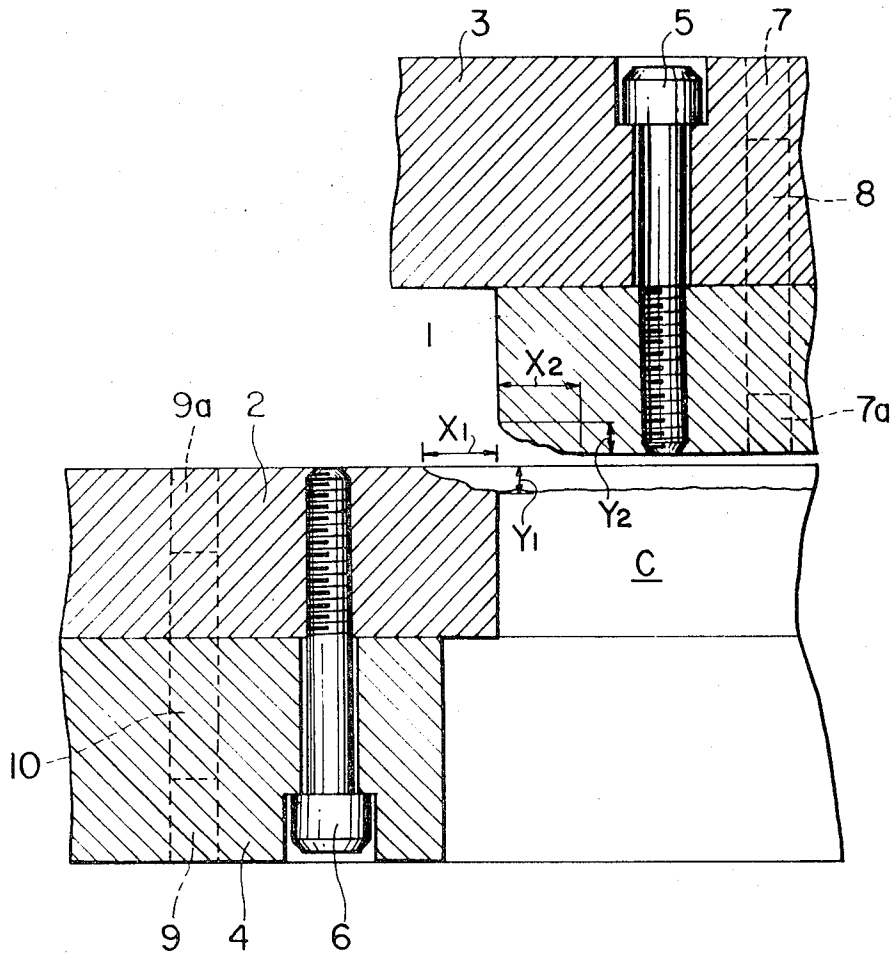
4 Sheets-Sheet 2

*Fig. 2*





*Fig. 4*



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## METHOD OF IMPROVING PUNCHABILITY OF STEEL SHEETS

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10 Claims

### ABSTRACT OF THE DISCLOSURE

A method of improving the punchability of electrical steel sheets and the like, by applying a first layer on the steel sheets, which contains one or more of chromic acid, chromates, and bichromates, and a second layer consisting of varnish on the first layer.

This invention relates to a method of coating electrical steel sheets, inclusive of silicon steel sheets, and more particularly to a method of coating steel sheets for materially improving its punchability.

In making cores of electrical equipments by using electrical core sheets or silicon steel sheets, e.g., cores of rotating machines and small power transformers, the electrical sheets are punched in a desired shape, and a plurality of sheets thus punched are assembled by lamination. If the punching causes too high burrs, the burrs may electrically connect adjacent sheets thus laminated, resulting in a deterioration of the electromagnetic properties of the core and other detrimental effects.

In practice, when the burrs become too high after repeated punching operations, the punching die is removed and ground, so as to reduce the burr. Such removal, grinding, and remounting of the punching die require extra man-hours and cost. Especially, in the case of progressive punching dies for making motor cores, the contour of each die is very complicatedly shaped and its grinding requires special skills. Accordingly, the efficiency of the punching process is lessened and the cost of the punching process increases by such burrs.

Thus, the punchability of electrical core sheets is very important for making laminated cores of electrical equipments, and a number of proposals have been made heretofore for its improvement.

The improvement of the punchability may be accomplished by improving the operating life of a punching die, or the number of punching operations which can be performed without re-grinding.

The critical allowable height of such burr, in the case of punching electrical core sheets, has empirically considered to be 40 to 80 microns, and a commonly used steel die will cause such critical burrs after 30,000 to 70,000 times of punching operation. The operative life of the punching die has recently been improved to 300,000 to 700,000 punching operations, or ten times of that of conventional steel dies, by using tungsten carbide alloys, such as WC-Co alloys.

The workability of iron and steel sheets to be punched has been the subject of many recent studies, and a number of reports have been published on the preferable mechanical properties of iron and steel sheets for the punching, such as hardness, yield point, and tensile strength. The improvement of punchability from the side of the iron and steel sheets is estimated to be at most in the doubling of the operative life of the punching die. Especially, in the case of electrical core sheets, the extent of chemical and thermal treatments of the sheets for the improvement of the mechanical properties is

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generally restricted by the need for providing the required electrical and magnetic properties. Thus, the room for improvement of the punchability of the electrical core sheets per se is much limited. For instance, Japanese patent publication No. 24,744/67, which was applied on Sept. 4, 1965 and published on Nov. 28, 1967, has disclosed an improvement of the punchability of steel sheets, but its improvement is at most 40 to 50%.

It is known that the punchability of steel sheets can be improved by applying varnish or enamel on steel sheets and baking the sheets with varnish or enamel thus applied thereto, for instance, as disclosed in AISI Proceedings, July 1968, "Flat Rolled Electrical Steel." Such varnish may double the number of satisfactory punching operations, for instance to 60,000 to 150,000 times without any re-grinding. On the other hand, such varnish consists of organic substance, and can stand only comparatively low temperatures, 300° C. at the highest, so that it cannot withstand high temperatures necessary for heat treatment of the iron and steel sheets, such as stress relief annealing (e.g., at about 800° C.). When a stator core is made by TIG (tungsten inert gas) welding, the varnish burns and causes a large number of blowholes, so as to greatly impair the mechanical strength of the weld beads. Such deterioration of the weld beads is a fatal shortcoming.

To obviate such difficulty, Japanese Patent No. 527,632, which was applied on Feb. 24, 1964 and published with publication No. 7,850/68 on Mar. 26, 1968, discloses the use of water-soluble inorganic coating, consisting of a main ingredient of chromic anhydride and other ingredients such as magnesium oxide and adipic acid. By baking steel sheets with such inorganic coating applied thereto, the punchability is improved to 1.5 to 2 times, as compared with that of conventional coating.

On the other hand, the last mentioned coating mainly consisting of chromic anhydride, a chromate, or a bichromate has shortcoming in that it causes extraordinary abrasion of the tungsten carbide alloy punching dies, so as to reduce the operative life of the punching dies to 200,000 to 500,000 punching operations. More particularly, when a tungsten carbide alloy punching die is used for processing steel sheets with the aforesaid inorganic varnish, the service life of the die is reduced to a level equivalent to one half or one fifth of that for processing uncoated steel sheets or steel sheets coated with a known phosphate film. Accordingly, such inorganic varnish of the last mentioned Japanese patent cannot be used with any tungsten carbide punching die.

Furthermore, both with the organic and the inorganic coating of known composition, the allowance for the punch-to-die clearance is small. Even if a test punching die of certain dimensions proved to be successful, the practical punching dies do not show good results for processing workpieces of complicated shape, such as motor cores.

In order to mitigate such difficulties of known techniques for punching iron and steel sheets, the inventors have made a series of studies and found that a composite coating, consisting of a first thin layer of chromic acid compounds and a second thin layer of varnish, acts to effectively suppress such burrs while making up for the inevitable dispersion of the punch-to-die clearance of the punching die, or the increase of such clearance during punching operation.

In fact, with the method of the invention, burrs inevitable in punching is greatly reduced and the die life can be improved by several tens of times.

According to the present invention, the service life of a punching die can be improved to 80,000 punching operations for steel dies, or to 5,000,000 punching operations for tungsten carbide alloy dies, simply by applying

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a composite coating on steel sheets, which composite coating consists of a first thin layer of chromic acid compounds and a second thin layer of varnish. With the method of the invention, it is not necessary at all to modify the chemical composition, mechanical properties, and electromagnetic characteristics of the steel sheets per se. The punching die can be used in conventional fashion, for punching steel sheets with the composite coating of the invention applied thereto, and the punching die does not require any special arrangement.

Furthermore, the method of the present invention can be applied to electrical core sheets containing 4% or less of Si. The composite coating applied to such electrical core sheets has excellent properties as an insulating coating of the electrical core sheets in various aspects; i.e., a high space factor, a high corrosion-resistivity, a high adhesivity, a high interlaminar resistance, and a high heat resistivity to ensure satisfactory welding and stress relief annealing.

More particularly, the present invention is to improve the punchability of steel sheets by using a composite coating on each of the steel sheets, which composite coating is formed by applying a first layer at 0.5 to 2.5 micron thickness, preferably 0.8 to 1.5 micron thickness, consisting of at least one compound selected from the group of chromic acid, chromates, and bichromates, and applying a second layer of 0.1 to 2.5 micron thickness, preferably 0.2 to 1.5 micron thickness, on the first layer, which second layer consists of varnish, and baking the coating.

The first layer of the composite coating according to the present invention is reddish brown, because the first layer contains six valent chromium ( $\text{Cr}^{+6}$ ). Such reddish brown colour of the first layer is maintained even if the layer contains a reducing agent of the chromic acid. When the second layer is overlaid on the first layer by applying a varnish thereon and baking, the reddish brown colour of the first layer, peculiar to six valent chromium, tends to be faded. Sometimes the finish composite coating presents greenish brown colour. If a steel sheet having the composite coating thus applied thereto is bent for separating the composite coating, both the first and the second layers of the composite coating flake off simultaneously as an integral coating. Thus, it seems that the first layer of chromic acid compounds may chemically react with the second varnish layer, so that at least a small part of the six valent chromium ( $\text{Cr}^{+6}$ ) may be reduced into three valent chromium ( $\text{Cr}^{+3}$ ). In other words, the chromic acid compounds of the first layer and the varnish of the second layer of the composite coating of the invention are firmly bonded together not only by physical adhesion but also by possible chemical bondage therebetween. The inventors assumed the possible presence of such chemical bondage based on the fact that a microscopic photograph of a cross section of the composite coating showed no boundary line between the first and second layers.

In a known single layer coating of chromic compounds applied on steel sheets, a suitable amount of a reducing agent is added thereto and fairly thorough baking is made, so as to reduce the hygroscopicity of the coating. With the method of the present invention, the need for such additional reducing agent is completely eliminated in applying the first layer of chromic acid compounds. Even if a reducing agent should be added in special cases, its amount can be very small. The heating of the first layer of the invention is for drying, and accordingly, it is heated at a low temperature for a short period of time. Thus, the first layer of the composite coating of the present invention need not be baked.

The amount of a reducing agent to be added in the first layer and the heating conditions thereof are determined, based on the time interval from the formation of the first layer to the application of the second layer of varnish. For instance, if the first and the second layers

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are applied continuously, mere drying of the first layer is sufficient.

The compounds for the first layer of the composite coating of the invention can be any water-soluble compounds of chromic acid, chromates, and bichromates.

Preferably chromic acid compounds to be used in the present invention are as follows.

- (1) Magnesium chromate, magnesium bichromate, or a mixture thereof.
- (2) Zinc bichromate, or a mixture of zinc bichromate and chromic acid.
- (3) Calcium bichromate, or a mixture of calcium bichromate and chromic acid.

One or more of the following inexpensive organic polyhydric alcohols may satisfactorily be used as a reducing agent of the chromic acid compounds, if it should be necessary: namely, ethylene glycol, diethylene glycol, triethylene glycol, glycerine, saccharose, grape sugar, etc.

It should be noted that if the first layer is thinner than 0.5 micron, the desired improvement of the punchability of the steel sheets cannot be achieved, whichever thickness of the second layer may be chosen. On the other hand, the inventors have found that if the first layer is thicker than 2.5 microns, the adhesion of the resultant composite coating to steel sheets is weakened. With the adhesion thus weakened, the composite coating tends to flake off from the steel sheets and the interlaminar resistance of electrical sheets tends to be reduced beyond allowable level. Furthermore, the flakes of such composite coating separated from the peripheries of steel sheets may pile on the surface of the die, to adversely affect the accuracy of the punching. The most favourable range of the thickness of the first layer has been found to be 0.8 micron to 1.5 microns.

For the second layer in the composite coating of the present invention, synthetic resin varnishes are more preferable than natural resin varnish. Some of the synthetic resin varnishes to be used in the present invention are as follows.

Phenol resin varnishes  
Amino resin varnishes  
Epoxide resin varnishes  
Silicon resin varnishes  
Polyamide resin varnishes  
Acrylic resin varnishes  
Melamine resin varnishes  
Polyester resin varnishes  
Vinyl resin varnishes  
Cumaron resin varnishes

A number of tests have been made on the above listed insulating varnishes to prove the satisfactory fulfillment of the object of the present invention.

The insulating varnish is usually dried at a temperature between room temperature and 180° C. If the varnish is excessively dried at an extra high temperature, pyrolysis is caused in the varnish to make the varnish layer fragile, so as to deteriorate adhesion of the varnish layer to the steel sheet and reduce the insulating strength of the varnish layer.

As an exceptional case, enameled wires and the like are dried at a comparatively high temperature, e.g., about 350° C., after applying enamel on bare conductors, for several tens of seconds, so as to improve the efficiency of the drying process. In this case, both the drying temperature and the duration of such heating treatment at an elevated temperature should be carefully controlled, for preventing the deterioration of flexibility and other mechanical properties caused by any excessive baking.

In the method of the present invention, to chemically bond the varnish to the first layer of chromic acid compounds, the baking should be done at a comparatively high temperature of 250° C. to 600° C., preferably

280° C. to 400° C., which temperature range has heretofore been avoided in the art of varnishing.

If the baking temperature is below 250° C., the desired improvement of the punchability and the accompanying high lubricating effects cannot be achieved, although acceptable adhesion of the coating can be obtained. For temperatures higher than 600° C., the baking time must be extremely short, and the control of such very short baking time is hard to make in actual installations.

The quick baking of the second varnish layer of the composite coating at such a high temperature affects not only the baking of the varnish layer but also the baking of the first layer of chromic acid compounds. Thus, the heat treatment of the first layer, prior to the application of the second layer thereon, can be very short.

The second layer of varnish should be at least 0.1 micron thick. Varnish layers thinner than 0.1 micron do not have satisfactory lubricating effects, which effects is of critical importance in the improvement of the punchability. On the other hand, if the thickness of the varnish layer exceeds 2.5 microns, its adhesion to the steel sheets is reduced to such an extent that its edges flake off during the punching operation, and the varnish layer edge portions thus flaked off pile up on the surface of the lower die, resulting in deformation of the steel or iron sheets being punched. Such excessively thick varnish layers are also prone to blowholes during TIG welding, because the varnish consists of organic compounds.

For a better understanding of the invention, reference is made to the accompanying drawings in which:

FIGS. 1 and 2 are graphs, illustrating the improvement of punchability, according to the present invention; and FIGS. 3 and 4 are schematic sectional views, illustrating the wear of a punching die assembly.

To demonstrate the effects of the present invention, examples of the present invention will now be described in comparison with some of the conventional methods, in terms of punchability.

FIGS. 3 and 4 illustrate the essential portion of a punching device, which was used in the following examples for testing the punchability of various steel strips or sheets. The punching device comprises a punch 1 secured to a movable die set 3 by bolts 5 and a female die 2 secured to a stationary die set 4 by bolts 6. In order to accurately align the punch 1 to the movable die set 3, knock pin holes 7 and 7a are bored therethrough, respectively. A knock pin 8 is hammered into the knock pin holes 7 and 7a after the latter holes are properly aligned, so as to firmly hold the punch 1 relative to the movable die set 3 during the repeated punching operations. Similarly, knock pin holes 9 and 9a are bored through the stationary die set 4 and the female die 2, respectively, and another knock pin 10 is hammered in the knock pin holes after the latter holes are properly aligned. Each of the steel sheets to be tested is placed on the top surface of the female die 2, which has a cavity R operatively engageable with the punch 1. As the punch 1 is lowered across the top plane of the female die 2, the steel sheet placed on the top of the female die 2 is punched by the coating punching edges P and Q of the punch 1 and the female die 2.

#### EXAMPLE 1

(1) Steel strips treated; Test steel strips (containing 0.018% of carbon, 0.30% of silicon, 0.029% of manganese, and 0.01% of phosphorus) of 0.5 mm. thickness with Hv (Vicker's hardness) of 128 were cleansed.

(2) Coatings and treating conditions;

(A) Coating of the invention;

A solution was prepared by adding 1.5 litres of ethylene glycol in 100 litres of a 17% solution of calcium bichromate, and the solution thus prepared was uniformly applied to the aforesaid test steel strips by a pair

of grooved rubber rolls. A first layer of 1.2 micron thickness was formed by heating each of the steel strips at 200° C. for 60 seconds in an electric furnace, and the steel strip was air cooled to room temperature. A phenol resin varnish was diluted by adding a suitable thinner, until its viscosity as measured by Ford Cup No. 4 became 15 seconds. The diluted varnish was applied on the first layer of the steel strips by a reverse type roll coater in the thickness of 0.5 micron, and then the varnish layer was baked at 350° C. for 80 seconds in a hot air furnace.

(B) Coating of chromic acid compounds;

A solution was prepared by adding 2.0 litres of ethylene glycol in 100 litres of 17% solution of calcium bichromate. Coatings of 1.2 micron thickness were made by uniformly applying the solution thus prepared on the aforesaid test steel strip by a pair of grooved rubber rolls, and baking at 300° C. for 100 seconds in an electric furnace.

(C) Varnish coating;

A phenol resin varnish was diluted by adding a suitable thinner, until its viscosity as measured by Ford Cup No. 4 became 40 seconds. The diluted varnish was uniformly applied on the aforesaid test steel strips, and then baked at 350° C. for 80 seconds in a hot air furnace, so as to form a varnish layer of 3.5 micron thickness.

(3) Punching tests; Punching tests were made by using a steel die (made of SKD-1 steel) with a punch-to-die clearance of 10 microns per side and a tungsten carbide die (made of WC-Co alloy with 16 wt. percent of Co) with a punch-to-die clearance of 15 microns per side. Disks of 20 mm. dia. were punched, while using a light oil lubricant. Three specimens were taken for every 10,000 disks thus punched, and the height of burrs was measured at four locations of each specimen by a dial gauge, and the mean value of the maximum burr heights of the three specimens was determined.

(4) Results, FIG. 1 illustrates the punchability of steel sheets with the aforesaid coating (A), (B), or (C), by using the steel die, while FIG. 2 illustrates similar punchability by using the tungsten carbide die.

It is apparent from FIG. 1 that with the conventional chromic acid compound coating or varnish coating, the burr height increased to 50 microns after 130,000 punchings and 190,000 punchings, respectively. On the other hand, with the coating of the invention, similar burr height was reached only after 800,000 punchings. Thus, with the method of the invention, the punchability was improved by four to six times, as compared with conventional methods. As shown by curve A' of FIG. 1, such improvement of the punchability of the present invention is not materially affected by increasing the punch-to-die clearance from the aforesaid 10 microns to 30 microns. Thus, the method of the present invention has a large allowance for the punch-to-die clearance.

Referring to FIG. 2, the tungsten carbide die can punch 1,200,000 times with the conventional varnish coating, but only 120,000 times with the conventional chromic acid compound coating, provided that the burr height should be less than 50 microns. On the other hand, with the coating of the present invention, the burr height did not exceed 20 microns even after 2,400,000 times of punching, by using the same test sheets and the same coating materials.

The wear of the tungsten carbide die used in the tests was measured by placing a thin copper sheet of 0.5 mm. thickness on each of the male and female die edges (P and Q in FIG. 3) after the punching tests, so as to reproduce the wear of such punch edge as an edge-like depression on the copper sheet. FIGS. 3 and 4 illustrate the conditions of the male and female die edges P, Q before and after repeated punching operations with the aforesaid coatings

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(A) and (B), respectively. With the test steel sheets having the aforesaid (B) coatings, the tungsten carbide die was worn to a considerable extent by 200,000 punchings; namely a wear of about 0.015 mm. in the horizontal direction, as shown by  $X_1$  and  $X_2$  in FIG. 4, and about 0.05 mm. in the vertical direction, as shown by  $Y_1$  and  $Y_2$  in FIG. 4. On the other hand, with the coating of the present invention, only slight wear of ordinarily experienced arcuate shape was noticed after 2,400,000 punchings.

The test results with the steel die prove that the lubricating effects of the coating of the present invention is superior to that of the conventional coating of chromic acid compounds and the coating of varnish alone. The test results with the tungsten carbide die show that the second layer of varnish covering the first layer of chromic acid compounds, in the coating of the present invention, acts to prevent the die from directly contacting the first layer.

To check the effects of the viscosity of lubricant oil, various lubricating oils were tested, ranging from a volatile lubricant with a low viscosity to a non-volatile lubricant with a high viscosity. It was proved that the coating of the invention gives excellent results, regardless of the foreseeable variation of the viscosity of the lubricating oil.

### EXAMPLE 2

A solution was prepared by adding 1.2 litres of glycine and 0.7 kg. of chromic anhydride in 100 litres of a 15% solution of magnesium chromate. A first layer of 1.8 micron thickness was formed by uniformly applying the solution thus prepared by a pair of grooved rubber rolls on the test steel sheets of Example 1, and drying the solution at 220° C. for 50 seconds in an electric furnace. The first layer was then cooled.

An amino resin varnish was diluted by a suitable thinner, until its viscosity as measured by Ford Cup No. 4 became 12 seconds. The diluted varnish was applied on the first layer by a reverse type roll coater in a thickness of 0.3 micron, and then baked at 320° C. for 70 seconds in a hot air furnace.

The test steel sheets with the coating thus formed were punched by a steel die with a 15 micron punch-to-die clearance, so as to produce disks of 20 mm. dia. The burr height was 50 microns after 950,000 times of punching.

### EXAMPLE 3

A solution, which consisted of 100 litres of 20% solution of zinc bichromate and 1.5 litres of glycerine, was uniformly applied to the test steel sheets of Example 1 by a pair of grooved rubber rolls, and then dried at 300° C. for 30 seconds in an electric furnace, to produce a first layer of 1.1 micron thickness. The first layer was cooled.

A terephthalate resin varnish was diluted by adding a suitable thinner, until its viscosity as measured by Ford Cup No. 4 became 20 seconds. The diluted varnish was applied to the first layer in a thickness of 0.8 micron by a pair of grooved rubber rolls, and then baked at 400° C. for 60 seconds in a hot air furnace.

The test steel sheets with such coating of the invention were punched by a tungsten carbide die with a punch-to-die clearance of 12.5 microns. The burr height was 25 microns after 2,800,000 times of punching.

As described in the foregoing disclosure, the coating of the present invention provides special lubricating effects to greatly improve the punchability of electrical core sheets. Furthermore, the coating presents excellent insulation. The interlaminar resistance of the electrical core sheets of the invention, as determined by the second method of JIS-C2550 (Japanese Industrial Standard) proved to be 30 to 60 ohm-cm.<sup>2</sup>/layer, which was comparable with the corresponding resistance of conventional electrical core sheets.

After laminating the steel sheets of the invention, the laminated edge was welded by the TIG welding. Excellent weld beads free from blowholes were obtained. The steel sheets thus welded were annealed at 750° C. for

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2 hours for the stress relief, but the first layer of chromic acid compounds remained as firmly bonded to the steel sheet while forming a very slight separation of the surface second layer. Thus, the steel sheets proved to be satisfactory for all practical purposes.

The excellent heat-resistivity of the coating of the present invention seems to be due to the fact that the first layer of chromic acid compounds is thicker than the second layer of varnish, and the very thin second layer of varnish acts to prevent the effects of heat decomposition of varnish from spreading beyond the thin layer itself, while maintaining the first and the second layers as an integral coating.

Thus, according to the present invention, there is provided a method for improving the punchability of steel sheets, especially electrical core sheets, while ensuring the necessary mechanical and electromagnetic characteristics. The coating of the present invention also has outstanding heat-resistivity to withstand welding and various other heat treatments. The coating of the invention reduces the wear and tear of punching tools, so as to improve the service life of such tools. It is also an important feature of the invention that such improvement of the punchability can be achieved independent of the inevitable dispersion of the punch-to-die clearance or the increase of the clearance. Thus, the invention does not require any extra care for mounting the punching tools. In short, the present invention contributes greatly to the improvement of punchability of steel sheets and the efficiency of the punching operation.

What is claimed is:

1. A method of improving the punchability of electrical steel sheets by applying a coating on each steel sheet, comprising the steps of forming a first layer of 0.5 micron to 2.5 micron thickness on the steel sheet by applying a solution containing at least one compound selected from the group consisting of chromic, acid, chromates, and bichromates, overlaying a second layer of 0.1 micron to 2.5 micron thickness on the first layer, said second layer consisting of varnish, and baking the layers at 250° C. to 600° C. so as to reduce at least a part of six valent chromium ions in the first layer to thereby suppress the anti-punching properties of the six valent ions.

2. A method according to claim 1, wherein said first layer is applied to a thickness of from 0.8 micron to 1.5 microns.

3. A method according to claim 1, wherein said second layer is applied to a thickness of from 0.2 micron to 1.5 microns.

4. A method according to claim 1, wherein said first layer contains at least one compound selected from the group consisting of magnesium chromate, magnesium bichromate, zinc chromate, zinc bichromate, calcium chromate, calcium bichromate, and chromic acid.

5. A method according to claim 1, wherein said first layer further contains a reducing agent selected from the group consisting of ethylene glycol, diethylene glycol, triethylene glycol, glycerine, saccharose, and grape sugar.

6. A method according to claim 1, wherein said second layer consists of varnish containing at least one resin selected from the group consisting of phenol resins, amino resins, epoxide resins, silicon resins, polyamide resins, acrylic resins, melamine resins, polyester resins, vinyl resins, and cumarone resins.

7. A method according to claim 1, further comprising the step of drying said first layer prior to the formation of the second layer.

8. A method according to claim 1, wherein said steel sheets are electrical core sheets.

9. A method according to claim 1, wherein said baking of the layers is carried out at a temperature 280° to 400° C.

10. A method of making punched electrical steel core elements comprising the steps of forming a first layer



of 0.5 micron to 2.5 micron thickness on a steel sheet by applying a solution containing at least one compound selected from the group consisting of chromic acid, chromates, and bichromates, overlaying a second layer of 0.1 micron to 2.5 micron thickness on the first layer, said second layer consisting of varnish, baking the layers at 250° C. to 600° C. and subjecting said steel sheet to a punching operation to produce said core elements.

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