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## METHOD OF MAKING ELECTRICAL CONDUCTORS

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This invention relates to electrical conductors and has for an object improvements in a method of making metallic conductors. More specifically the invention contemplates a method of making improved commutator segments for electromotive apparatus.

Heretofore it has been customary to make commutator segments by working solid copper bodies into the required size and shape. In the case of small commutator segments the practice has been to cut them from a hard drawn copper rod or wire of special shape. In cross section such rods or wires resemble that of a segment cut from a hollow cylinder through the axis thereof so that when the finished segments are aligned around the periphery of a commutator together with the insulating strips they form a substantially cylindrical ring. Rods or wires of this shape are difficult to make and hence the cost of manufacture is augmented. Furthermore, due to the irregularly shaped ends of commutator segments a considerable portion of the metal is discarded as trimming.

In the case of large commutator segments the usual practice is to work them out of rolled copper pieces in the cold state. Such working or pressing results in many uneven internal stresses in large commutator segments, and these stresses are frequently responsible for warping of the finished commutator.

Commutator segments and similar conductors are made at present from cold worked stock in order to obtain a hard conductor that will resist abrasion from the brushes of the electrical apparatus in which they are located, but cold fabricated copper is not entirely satisfactory for commutators on account of its tendency to warp and/or soften at elevated temperatures. It is common practice to bake motors and similar apparatus at a relatively high temperature for a considerable time in order to improve the character of the insulation. The effect of this baking is to anneal cold worked copper and render it very susceptible to abrasion. Furthermore, the baking operation allows a release of the interior stresses in cold worked copper, which often results in warping the commutator and sometimes ruins the whole apparatus.

It will be apparent from the foregoing discussion that the characteristics which are sought in a commutator segment are freedom from warping stresses at elevated temperatures, hardness after annealing, relatively high electrical conductivity, mechanical strength superior to ordinary cold worked copper, and a low coefficient of friction with brushes or other parts with which the commutator comes in moving contact. It should be equally apparent that the methods and materials now in use are not productive of all these advantages. Many efforts have been made to combine all these qualities in commutator segments, but in striving to improve one quality such as hardness, it has been necessary to sacrifice some other quality such as freedom from warping stresses or high electrical conductivity. On the other hand it should be noted that a slight reduction in conductivity is permissible, because the current density in a commutator is usually less than in the lead-in wire due to larger cross sectional area.

In the heretofore customary art of commutator manufacture efforts to substitute other metals and alloys for copper have met with little success, for the reason that cast metals and alloys do not combine the requisites for a good commutator. For example, steel while combining the advantages of greater hardness, higher mechanical strength, lower coefficient of friction and lower cost, does not make a satisfactory commutator, probably because its electrical conductivity is not sufficiently high.

As a result of my investigations, I have discovered that commutator segments combining all of the necessary characteristics in more or less degree may be produced by compressing finely divided metal powders in a suitable mold, heat treating the resultant mass at a temperature below the melting point and subsequently compressing the heat treated mass after it has cooled. By selecting the proper proportions of elements for the mixture of metallic powders, exerting the requisite amount of pressure, heat treating the material and repressing the metal in the cold condition to an adequate degree, I am able to produce commutator segments which are harder than ordinary cold worked copper, which do not warp or soften to an appreciable degree when held at elevated temperatures for long periods, and which combine sufficiently high electrical conductivity with high mechanical strength and a relatively low coefficient of friction.

According to a present preferred practice of my invention, metal powders in finely divided state (minus 325 mesh, Tyler scale) are combined in proper proportions, given a preliminary mixing, screened through 250 mesh to break up agglomerates and then mixed a second time in order to insure a thorough incorporation of ingredients. The mixture is then placed in a suit-

able mold and compressed into a coherent mass. It has been found that a pressure of at least 40 tons per square inch is desirable to produce a non-porous mass. I prefer to use a pressure of 50 tons per square inch. After compression the mass is subjected to a temperature of 630° C. for two hours in an atmosphere of hydrogen. Other reducing gases or inert gas may be substituted for hydrogen. The body is then replaced in the mold and subjected to a second compression under a force approximately equal to that used in the first compression treatment. The mechanical strength, hardness, resistance to warping and annealing, coefficient of friction and electrical conductivity of the finished mass will depend upon the metals employed, pressures, temperature and time.

I have found that copper powder, either alone or mixed with small amounts of powdered silver, cadmium, zinc, etc. or intermetallic combinations such as $Ag_2Cd_3$, $Ag_2Zn_5$, $Ag_3Sb$ or $Zn_3Sb$ etc., will retain the hardness imparted by the second or cold compression, when subjected to temperature of 235° C. for one hour. Such a treatment simulates that to which electromotive equipment is subjected when insulation is baked. Copper powder alone, when subjected to my process of compression, heat treatment and cold striking or compression, forms an electrical conductor having properties that are superior to those of ordinary cold worked copper. By adding small amounts of other metallic powders it is possible to increase hardness, resistance to annealing, and mechanical strength without sacrificing electrical conductivity to a degree which is intolerable in the manufacture of commutator segments. The following tabulation gives a series of hardness tests conducted upon commutator segments of my invention in which the admixture of other metals with copper was varied. In the case of the first eight samples, they were subjected to a second heat treatment for two hours at 630° C. in an atmosphere of hydrogen and to a second compression or cold striking. This was done in an effort further to increase hardness and resistance to annealing, but as will be observed, the tendency is to reduce these qualities. It is apparent that better results may be obtained with a single cold striking. In all cases the original and cold compressions were conducted at 50 tons per square inch, and all samples were subjected to a final heat treatment at 235° C. for one hour, after which they were allowed to cool slowly.

| Analysis | | | Brinell hardness determinations | | | | |
|---|---|---|---|---|---|---|---|
| No. | Percent copper powder | Percent of other powder ingredient | After first heat treatment for 2 hrs. at 630° C. in hydrogen | After first cold repressing at 50 tons per sq. in. | After second heat treatment for 2 hrs. at 630° C. in hydrogen | After second cold repressing at 50 tons per sq. in. | After baking for one hour at 230° C. |
| 1 | 100 | 0 | 46 | 74 | 48 | 67 | 67 |
| 2 | 99 | 1 Ag | 44 | 78 | 48 | 67 | 70 |
| 3 | 97.5 | 2.5 Ag | 44 | 78 | 50 | 70 | 71 |
| 4 | 99 | 1 Cd | 45 | 75 | 50 | 65 | 69 |
| 5 | 97.5 | 2.5 Cd | 39 | 74 | 50 | 70 | 69 |
| 6 | 98.5 | 1.5 Zn | 47 | 74 | 56 | 70 | 71 |
| 7 | 97 | 3 Zn | 43 | 77 | 56 | 71 | 71 |
| 8 | 98.5 | 1.5 $Ag_2Cd_3$ | 40 | 74 | | | 74 |
| 9 | 97 | 3 $Ag_2Cd_3$ | 34 | 77 | | | 74 |
| 10 | 98.5 | 1.5 $Ag_2Zn_3$ | 47 | 80 | | | 80 |
| 11 | 97 | 3 $Ag_2Zn_3$ | 44 | 80 | | | 80 |
| 12 | 98.5 | 1.5 $Ag_3Sb$ | 45 | 80 | | | 74 |
| 13 | 97 | 3.0 $Ag_3Sb$ | 39 | 80 | | | 74 |
| 14 | 98.5 | 1.5 $Zn_3Sb$ | 46 | 83 | | | 80 |
| 15 | 97 | 3 $Zn_3Sb$ | 49 | 86 | | | 74 |

These results conclusively demonstrate that the process produces commutator segments which are not deleteriously affected by baking, whereas the ordinary cold worked copper segments of the prior art are rendered soft and non-resistant to abrasion. Furthermore, careful measurements of the segments before and after baking indicate that no distortion occurs.

Resistance measurements of commutator segments produced by the process of my invention indicate that the conductivity may be closely controlled by varying the powder ingredients and the temperatures and the pressures of treatment. In general it may be said that the conductivity increases during the first compression of the powders prior to heating almost in direct ratio to the pressure exerted. Tests on a compressed mass of copper powder of a grain size varying from 150 to 300 mesh prior to heat treatment gave the following results:

| Pressure exerted—short tons, sq. in | 50 | 75 | 100 |
|---|---|---|---|
| Percent conductivity Bureau of Standards basis | 53 | 72 | 92 |

However, when cold striking after heat treatment is employed the conductivity increases much more markedly with respect to the pressure exerted. Copper powder of the same grain size as in the tests referred to above, was subjected to a pressure of 50 tons per square inch, heat treated at 630° C. for two hours and after cooling was again compressed at 50 tons per square inch. In this case the final conductivity was superior to that of copper conductors produced by the heretofore customary methods.

The ability to increase conductivity to the extent indicated permits the admixture with copper powder of substantial quantities of powdered metals with a lower conductivity than copper in order to obtain increased wearing qualities in the finished commutator segments. Thus additions of several percent of silver, cadmium, zinc and similar metals or intermetallic combinations whose presence does not decrease conductivity of copper to an excessive degree, result in a commutator segment of greatly improved physical properties which is at the same time possessed of the desired electrical conductivity.

As was previously stated, the heretofore customary practice of commutator manufacture has required special extruded copper shapes and has resulted in much loss of metal in trimming. Consequently the cost of manufacture has been high, so high in fact that my invention should be able to compete commercially with prior proc-

esses, notwithstanding the fact that the cost of making the metal powders is included in the cost of commutators made in accordance with my invention. Furthermore, the improved qualities of the commutator segments of my invention tend to increase the life and to decrease the operating cost of electrical equipment into which they are incorporated.

The application of my invention is not limited to commutator segments. Many other electrical conductors may be made advantageously by compressing metallic powders, heat treating and compressing the resultant mass a second time. Such conductors are particularly desirable where they are required to come into moving contact with other parts, but they are also applicable under other and less stringent conditions of use.

I claim:

1. A method of making a commutator which comprises forming commutator segments by compressing and sintering metal powders to form coherent substantially non-porous masses, subjecting these masses to compression in the cold state to form hard commutator segments, incorporating the segments into the commutator, and then subjecting it to baking.

2. A method of making a commutator which comprises forming a commutator segment by compressing and heat treating copper powders to form a non-porous coherent mass, compressing said mass in the cold state, incorporating the cold pressed mass into the commutator, and baking it.

3. A method of making a commutator which comprises forming a commutator segment by compressing and sintering a mixture of copper powders with metal powders selected from the group consisting of silver, zinc, cadmium, antimony and intermetallic combinations of these metals to form a coherent substantially non-porous mass, and then subjecting the mass to compression in the cold state until its density is increased, incorporating the commutator segment thus formed into a commutator, and baking it.

4. In the manufacture of electrical machinery containing a conducting and wearing part of metal of accurate configuration which, when in place in said machinery, is subjected to heat under conditions such that the part tends to warp, the improvement which comprises forming the part by compressing and sintering metal powders to form a coherent substantially non-porous mass, subjecting said mass to compression in the cold state to increase its hardness, then placing said part in the machinery and subjecting it to baking in place.

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