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NICKEL-SILICON ALLOY PRODUCT

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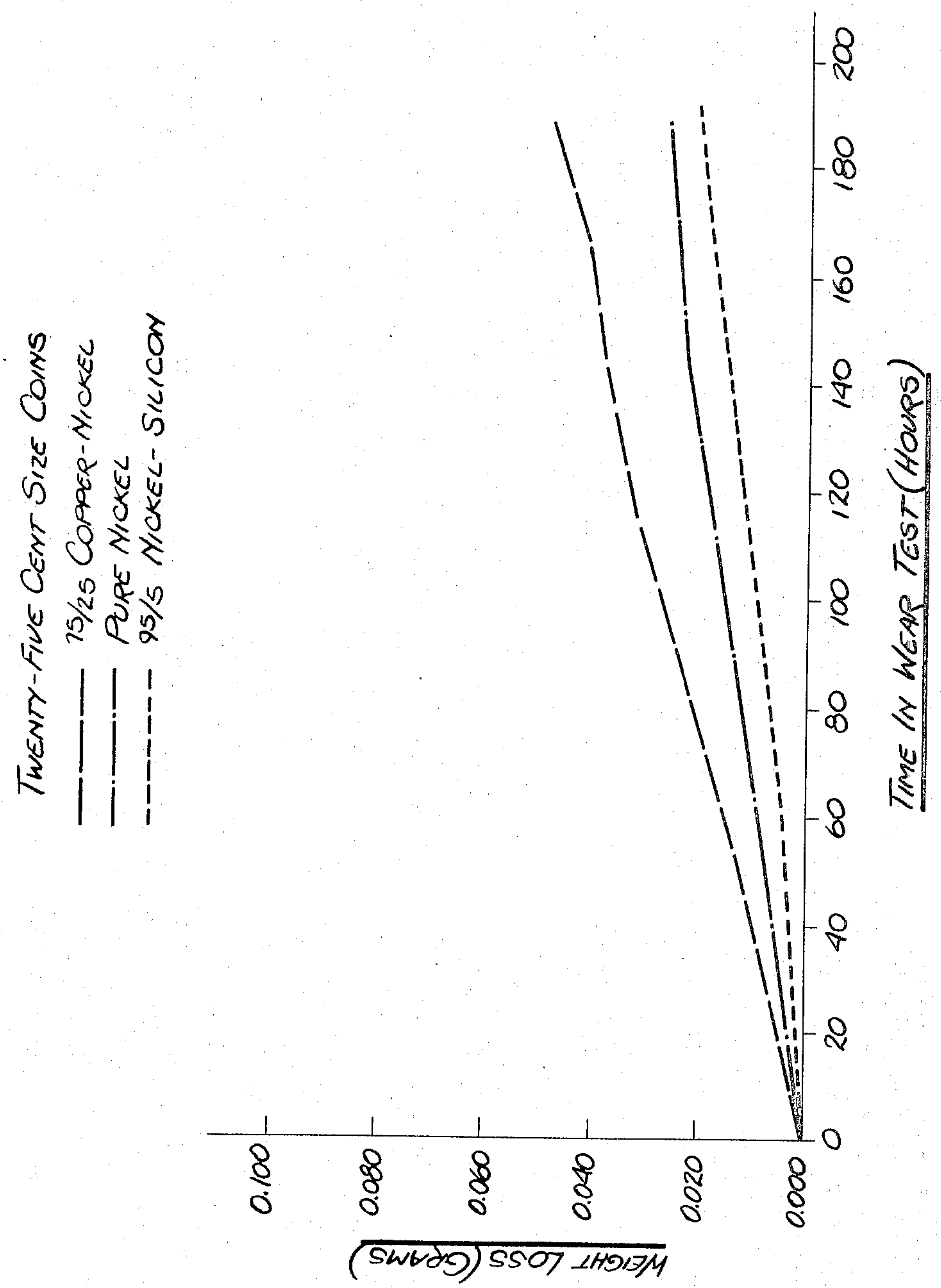

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NICKEL-SILICON ALLOY PRODUCT

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ABSTRACT OF THE DISCLOSURE

Directed to a new coinage material having a particularly advantageous combination of properties for coinage purposes, such properties include a low Curie temperature, good workability, both hot and cold, good embossability, high resistance to corrosion, tarnishing and wear, controlled resistivity and density, and a bright silvery color; the material being made of a nickel-silicon alloy containing about 5% silicon.

The present invention is directed to an improved coinage alloy and, more particularly, to a nickel-base alloy coinage material having an outstanding combination of coinage properties and characteristics.

Metallic coins have been in use for centuries and it is fair to say that metallic coinage is essential for the purpose of transacting business in any advanced civilization. The problems of producing a satisfactory coinage are many and diverse, although these problems usually are taken for granted since coins and their usage are an integral part of daily life. The issuance of metal coinage has from earliest times been a prerogative of the sovereign and it has always been considered that from the standpoints of public acceptance of, and confidence in, the coinage that the use of metals having substantial intrinsic value and good appearance would be required. Many different metallic alloys, including bronze and other copper alloys, gold, silver, nickel and nickel alloys, and other allows have been used in coinage from time to time depending upon a myriad of factors. In modern times, the use of gold in coinage has disappeared and recent technical advances pertaining to the industrial uses of silver have created such a demand for this metal that consideration is being given to the replacement of silver as a coinage metal.

Another fairly recent occurrence which has affected the use of coinage in the United States and other countries is the widespread adoption of coin-operated vending machines. While such machines have been in use for years, their acceptance for a great variety of vending purposes has been increasing at an accelerating rate in recent times. One of the results of the relatively recent accelerated use of vending machines has been an acuate shortage of coins in the United States.

The metallurgical requirements which must be met in providing a satisfactory coinage material, even absent the factor of vending machines, are stringent. Thus, the coin should be bright and resistant to tarnishing in order to secure public acceptance. For example, aluminum has been employed in certain countries for low denomination coinage but this metal becomes dull and unattractive in appearance during handling in circulation and, furthermore, it has a poor "ring" which makes it unattractive and undesirable as a coinage material. Another example of an "ersatz" coinage material is the zinc plated steel one cent coin which was employed in the United States due to exigencies of the wartime period. The appearance of these coins deteriorated rapidly during the circulation thereof and they were withdrawn from circulation. In addition, the coinage metal should be capable of ready processing

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into strip. This factor imposes the requirement of good hot and cold malleability, the ability to take a good surface upon cold rolling, and the capability of being embossed in the coinage dies to produce a sharp, clear impression thereon. These additional requirements further limit the choice of a coinage metal to materials having high ductility and workability.

The introduction and use of coin-operated vending machines, which has taken place at an accelerated rate, complicates the coinage problem even further. Thus, it has been an altogether too common practice for unscrupulous individuals to attempt to operate vending machines by means of spurious or counterfeit coins, slugs, etc. While such attempts have been many and ingenious, the vending machine art has for the most part kept ahead of the counterfeiter and cheater by means of coin rejector mechanisms which are carefully constructed so as to discriminate between valid coins and counterfeits or slugs. The widespread usage of vending machines, which have built into them coin-discriminating devices of a highly sophisticated nature, now makes it advisable that any coinage material which would be used as a substitute for present day coinage materials be accepted in vending machines to the same degree as present day coinage alloys. Thus, the still further factor of interchangeability with present coinage alloys is advisable for any proposed new coinage alloy because of the present very large investment in vending machines. The coin-discriminating devices which have come into use in coin-operated vending machines subject the coin to a number of tests which measure the coin for weight, size, electrical resistivity, hardness, and magnetic properties. For example, the discriminating circuits employed in common vending machines designed to accept the present day cupronickel (about 75% copper, balance nickel) United States five cent coin are equipped with a slot which guides the inserted coin through a device which tests the coins for size and thickness. Improperly dimensioned coins or slugs are rejected and, if the coin is perforated, it will be caught by a hook located in the path of travel and be discarded. Coins which pass these tests are then carried over a transfer cradle which checks the weight. At this point, low-density or underweight coins are rejected. If it is still acceptable after these tests have been performed, the coin is rolled down a runway through a magnetic field which checks the electrical resistivity and magnetic properties of the coin. Thus, if the coin is strongly ferromagnetic, e.g., steel, pure nickel, etc., it will be held by the magnet and thus prevented from freeing the vending machine mechanism. Thus, acceptable coins must be essentially nonmagnetic. Again, if the electrical resistivity is not within a carefully defined range, the coin will be rejected by the mechanism. Thus, the speed of the coin down the runway through the magnetic field is affected by induced eddy currents with coins of lower electrical resistivity being slowed during passage down the runway to a greater extent than coins of higher resistivity. At the end of the runway past the magnet, the coin follows a parabolic trajectory, hits a striker plate, and rebounds. If the coin is unsatisfactory in terms of its electrical resistivity or its hardness, it will not follow the prescribed trajectory beyond the striker plate and will accordingly be rejected. The five cent coin circuit in vending machines is set to accept properly dimensioned coins made of a cupronickel alloy containing about 75% copper, balance nickel, having a density of about 8.9, an electrical resistivity of about 30 to 35 microhm-centimeters, and a Curie temperature below about zero degrees F.

We have now discovered a new nickel-base coinage material which is accepted by coin-discriminating devices designed to pass cupronickel coinage such as the standard U.S. five cent coin and many foreign coins, and which posssesses to an outstanding extent desirable coinage properties of appearance, resistance to tarnishing, hot and cold malleability, ability to receive a sharp impression in coining dies, low Curie point, controlled resistivity, wear resistance, and intrinsic value.

It is an object of the present invention to provide a nickel-base alloy coinage material having an outstanding combination of properties, including controlled resistivity, low Curie temperature, high wear resistance, good appearance, and resistance to tarnishing.

It is a further object of the invention to provide nickel-base alloy coins having a sharp embossed impression, good appearance, resistance to tarnishing and interchangeability with standard cupronickel coinage material.

It is still another object of the invention to provide coinage strip and coins having superior wear resistance and resistance to tarnishing as compared to standard cupronickel alloy coinage materials.

Other objects and advantages of the present invention will become apparent from the following description taken in conjunction with the accompanying drawing which depicts the results of an accelerated wear-corrosion test as applied to the coinage material of the invention.

Generally speaking, the present invention is directed to coinage strip and coins made of a special nickel alloy containing about 4.85% to 5.6% silicon with the balance of the alloy being essentially nickel. More advantageously, the alloy contains about 4.85% to about 5.15% silicon since such alloys are characterized by a resistivity which does not exceed about 40 microhm-centimeters, e.g., about 35 to about 40 microhm-centimeters, and coins made thereof are interchangeable in coin-discriminating devices having a resistivity test designed to accept cupronickel coins such as the U.S. five cent piece. In addition, such more advantageous alloys possess high ductility in that strip made therefrom can be bent 180 degrees about a radius equal to the thickness of the strip without cracking. In addition, such alloys are characterized by a broad hot working range and by freedom from edge cracking on rolling whereas with silicon contents exceeding about 5.6% edge cracking of hot rolled strip has been observed.

The coinage strip and coins contemplated in accordance with the invention are made of an essentially binary nickel-silicon alloy having a carefully controlled silicon content as described hereinbefore. The alloy contains about 0.02% carbon, e.g., 0.01% to about 0.05% carbon, less than about 0.1% iron, less than 0.2% cobalt, and less than about 0.1% manganese. In common with other high-nickel alloys, the sulfur content of the alloy is maintained as low as possible and does not, in any event, exceed about 0.01% so as to avoid the detrimental effect of sulfur on the malleability of the alloy. For the same reason, the contents of impurities such as lead and phosphorus are maintained below about 0.01% each. Carbon, iron and cobalt detrimentally affect the required properties possessed by the coins and coinage strip contemplated in accordance with the invention. Thus, carbon detrimentally raises the electrical resistivity of the material. Cobalt and iron detrimentally raise the Curie transition temperature. This factor requires that high purity silicon be employed in preparing the alloy. Common ferrosilicon alloys are not satisfactory. The alloy may be deoxidized by means of elements such as aluminum and magnesium but residual quantities of these deoxidizers in the coinage material does not exceed about 0.1% each. Copper is maintained at low levels not exceeding about 1%, since the presence of copper in any material quantity limits the silicon range, raises the hardness, and makes it exceedingly difficult to provide a nickel-silicon alloy coinage material having the required low Curie temperature coupled with a resistivity not exceeding about 40 microhm-centimeters.

The special coinage material contemplated in accordance with the invention is characterized by excellent hot workability and cold workability which facilitates the production of coinage strip.

The special coinage material can be produced in conventional air melting equipment and can be reduced to strip using conventional forging, hot rolling, annealing, and cold working techniques. While it is advantageous, as noted hereinbefore, to maintain the silicon content in the special nickel coinage material within the limited range of 4.85% to 5.15%, it is found in practice that this silicon range can be met repeatedly and on a commercial scale. The close control of the silicon content which is required makes counterfeiting coins made of the special alloy a difficult matter since technical control of the melting operation is required. Coinage strip and coins produced in accordance with the invention possess to a remarkable degree a combination of mechanical and physical properties which makes the material exceedingly useful in coinage service. Thus, coins produced in accordance with the invention have a bright, slivery color and have a good ring which is superior to the cupronickel alloy currently employed in the production of the U.S. five cent piece. In addition, the alloy is nonmagnetic as indicated by a Curie temperature not higher than zero degrees F. The coinage material is characterized by high resistance to corrosion and high resistance to tarnishing when handled in service. Further, the coins produced are highly resistant to the kinds of wear which are encountered in coinage service and thus have the potential for long service life. It is found that the coins and coinage strip contemplated in accordance with the invention have a hardness in the annealed condition of about 60 Rockwell "B." The material hardens under cold working such that the hardness after 10% cold work is about 90 Rockwell "B," after 25% cold work is about 102 Rockwell "B," and after 50% cold work is about 107 Rockwell "B." The cold worked material can be annealed at temperatures of about 1300° F. to about 2000° F. for about 10 to about 40 minutes, e.g., about 1750° F. for about 20 minutes. In producing coins from the material, it is desirable to cold work annealed strip about 20% to provide a hardness of about 100 Rockwell "B" for the blanking operation. The blanks are then formed and are annealed in a nonoxidizing atmosphere to a hardness of about 60 Rockwell "B" after which the blanks are embossed. In the embossing operation, the hardness is increased to about 100 Rockwell "B." The coins take a sharp impression from the embossing dies and it is found that die wear is not excessive but is about on the same order as is encountered with a 75% copper, 25% nickel alloy currently employed in the production of the U.S. five cent piece.

The special combinations of resistivity and Curie temperature obtainable in coinage materials produced in accordance with the invention are illustrated in the following Table I:

TABLE I

Alloy No.	Percent Nickel	Percent Silicon	Resistivity, ity, Microhm-centimeters	Curie Temperature, ° F.
1	95.1	4.89	38.55	−68
2	95.1	4.90	38.15	−53
3	94.8	5.1	39.35	−60
4	94.5	5.4	40.0	−100

The importance of controlling the silicon content of coinage materials contemplated in accordance with the invention is illustrated by the properties of an alloy strip outside the invention containing 95.2% nickel and 4.8% silicon. This alloy strip had a higher resistivity in the same condition as given for the strips in Table I of 39.58 microhm-centimeters and an unacceptably high Curie temperature of 25° F.

The resistance of coinage materials produced in accordance with the invention to the combined effects of wear and corrosion as compared to a cupronickel alloy containing 75% copper, balance nickel, and to pure nickel was demonstrated by an accelerated wear-corrosion test.

The accelerated wear-corrosion test consisted of continuously tumbling about 25 test coins in a baffled ceramic drum having a capacity of about two gallons containing about 15 pounds of a solid charge comprising keys, pennies, 2 inch squares of leather, corks, canvas, rough-edged Hastelloy C shot and a solution of artificial perspiration comprising 40 grams NaCl, 5 grams Na_2HPO_4, 4 milliliters lactic acid, and distilled water to make 4 liters of solution (as reported by S. J. Eisler and H. L. Faigen, "Investigation of Synthetic Fingerprint Solutions," Corrosion, Nace, August 1954). The coins were periodically cleaned and weighed. The weight loss determined upon test coins in the accelerated wear-corrosion test is depicted in the accompanying drawing. The results indicate that, after 190 hours in the accelerated test, test coins made of the nickel-silicon alloy of the present invention displayed a wear resistance nearly 2½ times better than test coins made of a standard 75% copper-25% nickel coinage alloy and displayed a resistance to the combined effects of wear and corrosion about 1½ times better than pure nickel test coins. It further can be said that the test coins made of the special nickel-silicon alloy displayed a resistance to the effects of combined wear and corrosion on the order of 4½ times better than current U.S. silver alloy coinage. The weight loss suffered by the nickel-silicon alloy test coins was at a projected rate of only about 1.5 milligrams per year as indicated in the accelerated test.

In manufacturing the coinage material contemplated in accordance with the invention, conventional air melting practice may be employed, for example, the air induction furnace is quite satisfactory. The following melting practice employing an air induction furnace has been found completely satisfactory:

(1) Charge high purity nickel material such as electrolytic nickel with about 0.05% nickel oxide.

(2) Melt down and heat to about 2700° F.

(3) Hold at temperature for about three minutes to permit reaction between the nickel oxide and reactive impurities present.

(4) Add a silicon deoxidizing addition amounting to 0.05% by weight of the charge.

(5) Permit the melt to cool until it starts to freeze and add silicon metal slowly. The addition of silicon is exothermic and cooling of the melt is helpful to compensate for the temperature increase in the melt due to silicon addition.

(6) Adjust the bath temperature to about 2575° F.

(7) Deoxidize the melt by plunging about 0.05% aluminum metal and then add about 0.05% magnesium as a nickel alloy containing about 15% magnesium.

(8) Adjust the melt temperature to about 2575° F. and cast into ingot molds.

(9) Heat the ingots to about 2100° F. and forge.

(10) Reheat the forged ingots to about 2100° F. and hot roll from about 0.5 inch to about 0.15 inch.

(11) Cold work the hot rolled strip without annealing to about 0.07 inch.

(12) Anneal at about 1750° F. for about 5 to 10 minutes in a protective atmosphere.

(13) Cold roll to about 0.065 inch (about 10% cold work) for blanking.

It is desirable to clean the surface of the ingot before hot working and of the hot rolled strip before cold rolling by conventional means such as pickling, grinding, etc. In annealing the coinage material, protective atmospheres such as dry hydrogen, cracked ammonia, dried partially combusted natural gas, a dry gas mixture containing about 90% nitrogen and 10% hydrogen, etc., may be employed.

Investigations of other nickel-base alloy systems have demonstrated that the coinage material contemplated in accordance with the present invention possesses a unique combination of properties to a remarkable extent. These investigations have included nickel-base alloy systems wherein vanadium, aluminum, titanium, chromium and copper have been employed in place of, or in combination with, silicon. It has been found that all of these alloy systems have possessed undesirable properties in various respects as compared to the essentially binary nickel-silicon alloy coinage material contemplated in accordance with the present invention. Thus, titanium and aluminum form stable compounds, believed to be Ni_3Ti and Ni_3Al, respectively, and the resulting alloys are magnetic, age-hardenable and provide poor coinage die life. Accordingly, the resulting alloys are unsatisfactory as coinage materials.

It was also found that chromium additions to nickel quickly raise electrical resistivity to unacceptable high levels for coinage purposes and produce hard alloys which lower coinage die life. Certain alloy combinations in the nickel-silicon-vanadium alloy system containing about 5% to less than 6.5% silicon plus vanadium can give certain desirable properties for coinage purposes, but these combinations do not provide a combination of a resistivity less than 40 microhm-centimeters with a Curie point less than zero degrees F. Furthermore, these alloys are attended by serious practical drawbacks making them much less satisfactory than the special nickel-silicon coinage materials to which the present invention is directed. Thus, vanadium of acceptable purity to meet requirements is very expensive and vanadium-containing ferroalloys cannot be used because the accompanying iron is ruinous to the Curie temperature and resistivity properties required in nickel alloy coinage materials. In addition, vanadium provides practical difficulties in air melting since vanadium additions of the requisite order generate a sticky slag which is very difficult to handle. This problem can be overcome by vacuum melting and/or vacuum treating, but these expedients raise the cost of melting very considerably. This factor, coupled with the high cost of vanadium metal, make coinage materials produced from the alloys uneconomic. Alloys within this grouping together with the electrical resistivity and Curie temperatures developed in strip produced therefrom in the annealed condition are given in the following Table II:

TABLE II

Alloy No.	Percent Nickel	Percent Silicon	Percent Vanadium	Resistivity Microhm-centimeters	Curie Temperature, ° F.
----------	93.1	1.55	4.40	43.95	25C
----------	93.5	2.12	3.80	43.56	5A
----------	93.9	3.16	2.0	39.51	35B

It will be seen from the foregoing Table II that the given properties of these nickel-silicon-vanadium alloys are decidedly inferior to the same properties of the binary nickel-silicon alloy coinage materials contemplated in accordance with the invention. For example, Alloy C, the only alloy having a resistivity below 40 microhm-centimeters, had an impermissibly high Curie temperature of 35° F. Temperatures of this order and lower temperatures are encountered under ordinary ambient conditions and would cause a coin made from the alloy to become magnetic whereupon it would be rejected by a vending machine.

Certain nickel-silicon-copper alloys can possess acceptable combinations of resistivity and Curie temperature for use as coinage materials. An alloy strip containing 4.53% silicon, 4.9% copper, balance nickel, had an undesirably high resistivity of 43.67 microhm-centimeters and a Curie temperature of minus 88° F. However, the compositional ranges in this system which will provide the requisite combinations of resistivity and Curie temperature are so narrow that it is not practical to employ them commercially for the production of coinage materials. Thus, even very minor variations in composition can cause unacceptably wide increases in both Curie temperature and resistivity with the result that a large proportion of scrap heats would be encountered in commercial operation, with concomitant increases in cost.

Coins contemplated in accordance with the invention are accepted without adjustment by the coin-discriminating devices currently employed in vending machines to accept the U.S. five cent piece. It is found, however, that adjustment of the vending machine discriminating circuits is required before coins made in accordance with the invention can be accepted by the discriminating circuits employed in vending machines to accept valid U.S. ten cent, twenty-five cent, fifty cent, and one dollar coins. This latter factor reflects the substantially high resistivity of the coinage material contemplated in accordance with the invention as compared to the low resistivity, e.g., about 2 microhm-centimeters, of the 90% silver-10% copper alloy currently employed for U.S. silver coins.

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

We claim:

1. As a new article of manufacture, coinage strip made of an alloy consisting essentially of about 4.85% to about 5.15% silicon, with the balance of the alloy being essentially nickel, said strip being characterized by a Curie temperature not higher than about zero degrees F., a hardness in the annealed condition of about 60 Rockwell "B" and in the embossed condition of about 100 Rockwell "B," good hot workability and cold workability, high resistance to corrosion, tarnishing and wear, good embossability, a resistivity not exceeding about 40 microhm-centimeters, a density of about 8.6 grams per cubic centimeter, and by a bright silvery color.

2. As a new article of manufacture, a coin made of an alloy consisting essentially of about 4.85% to about 5.15% silicon, with the balance of the alloy being essentially nickel, said coin being characterized by a Curie temperature not higher than about zero degrees F., a hardness in the embossed condition of about 100 Rockwell "B," good hot workability and cold workability, high resistance to corrosion, tarnishing and wear, good embossability, a resistivity not exceeding about 40 microhm-centimeters, a density of about 8.6 grams per cubic centimeter, and by a bright silvery color.

3. As a new article of manufacture, coinage material made of an alloy consisting essentially of about 4.85% to about 5.6% silicon, with the balance essentially nickel, said coinage material being characterized by a Curie temperature not higher than about zero degrees F., good hot workability and cold workability, high resistance to corrosion, tarnishing and wear, and by a bright silvery color.

4. As a new article of manufacture, coinage material made of an alloy consisting essentially of about 4.85% to about 5.15% silicon, with the balance essentially nickel, said coinage material being characterized by a Curie temperature not higher than about zero degrees F., good hot workability and cold workability, high resistance to corrosion, tarnishing and wear, and by a bright silvery color.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,367,773 February 6, 1968

Pierre P. Turillon et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 41, "allows" should read -- alloys --; line 55, "acuate" should read -- acute --. Column 4, line 19, "slivery" should read -- silvery --; TABLE I, fourth column heading, cancel "ity,", second occurrence. Column 6, TABLE II, first column, lines 1, 2 and 3 thereof, insert -- A --, -- B --, and -- C --; same table, sixth column, lines 1, 2 and 3 thereof, "25C", "5A" and "35B" should read -- 25 --, -- 5 --, and -- 35 --.

Signed and sealed this 23rd day of September 1969.

(SEAL)
Attest:

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Commissioner of Patents