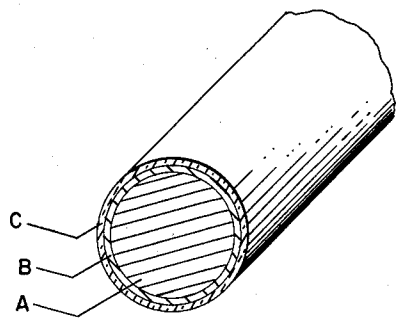
Oct. 29, 1963 J. F. AHEARN 3,109,053

INSULATED CONDUCTOR

Filed Jan. 5, 1961



A	B	C
		BONDING AGENTS
SILVER	CHROMIUM	VITREOUS MATERIALS
COPPER	RHENIUM	LEAD BORATE
	IRON	LEAD SILICATE
	(alloys of above)	(combinations of above)
		MIXTURE OF SODIUM POTASSIUM SILICATES
		CALCIUM SILICATES
		REFRACTORY MIXED WITH BONDING AGENT
		ALUMINUM OXIDE
		TITANIUM OXIDE
		ZIRCONIUM OXIDE
		BERYLLIUM OXIDE
		GROUND MICA
		QUARTZ FIBRE
		ALUMINUM SILICATE
		POTASSIUM TITANATE
		ASBESTOS
		OTHERS
		FLUORIDE COMPOUND

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INSULATED CONDUCTOR

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This invention relates to methods and means of construction of insulated conductors such as magnet wires and ribbon conductors which are required to operate at elevated temperatures.

Insulated conductors for high temperature service have employed as insulation either a Fiberglas serving or a ceramic coating. Fiberglas is capable of withstanding temperatures up to about 650° C. without deterioration of the insulation. However, due to the bulk of the Fiberglas serving, the space factor of Fiberglas served magnet wires is very poor compared with most organic film insulated wires. The relative volume occupied by the insulation becomes increasingly greater as the diameter of the wire becomes smaller, with the result that the volume of copper wire, for instance, in a typical magnet coil winding is only about 11 percent of the total volume of the winding. Using single glass serving, the volume of conductor is 23 percent of the total volume. These values are very low compared with the space factor of 55 percent for many conventional organic film coated wires. Therefore, any major improvements in space factor of glass served wires is most difficult because of the minimum size of yarn which can be produced and handled on wire-serving machinery.

Ceramic coatings have been applied in very thin layers to metal, yielding an insulated wire of space factor equivalent to or better than that of organic film coated conductors. However, prior to the present invention, no method was known whereby an adherent, flexible ceramic coating could be applied to popular conductor metals, such as silver and copper. Methods are known for applying inorganic oxide coatings to aluminum by means of the anodizing process. However, aluminum has only 61 percent of the conductivity of annealed copper and is therefore not suitable for applications in which size and weight are important considerations. In addition, the low melting point of aluminum (650° C.) limits its use to temperatures less than about 500° C. Ceramic insulation comprising refractory oxides bonded with glass has been applied with considerable success to nickel clad copper wires. Such coatings exhibit a remarkable degree of adherence and flexibility due to the fact that a molecular bond exists between the nickel base metal, a diffused nickel oxide, and the ceramic-glass insulating layer. However, nickel clad wires which have been successfully coated with ceramic have initially only about 70 percent of the conductivity of pure copper, and upon aging at elevated temperatures, a portion of the nickel diffuses into the copper core of such wires forming a copper-nickel alloy of much higher resistance than pure copper. Consequently, aging of nickel clad copper wires at elevated temperatures even in the absence of air results in a permanent increase in the resistance of the wire. The extent of resistance increase is dependent on the wire diameter, the temperature, and the time of exposure to high temperature.

The lack of an available high temperature insulated conductor combining the desirable properties of good space factor, high conductivity, thermal stability, flexibility and mechanical durability has imposed a severe handicap on the design of electronic equipment which is required to operate at temperatures of 250 to 600° C. It is an object of the present invention to provide an insulated

conductor having the above-mentioned requirements and which exhibits little or no change in resistance when subjected to prolonged exposure to elevated temperatures up to 600° C. The single FIGURE shows a laminated structure embodying my invention, the composition of the various laminae also being listed.

In accordance with the present invention and as illustrated on the drawing, a high temperature insulated conductor is prepared by plating or otherwise imposing upon a high conductivity base metal A (such as silver or copper) a layer B of chromium, rhenium or iron or alloys thereof so as to comprise roughly from 1 to 10 percent of the total volume of the conductor. The precise proportion by weight of the plating metal or alloy to the base metal varies with the diameter of the wire but should be sufficient to protect the base metal conductor from the effects of oxidation when heated in air to 800° C. for a period of five minutes. Methods of electro-plating or forming chromium, rhenium or iron on copper or silver are known to the art and do not constitute a part of this invention.

Subsequent to plating, an oxidized surface is caused to form upon the plating metal or alloy by any of several possible methods, among which are (1) heating in air or oxygen for short periods at 600 to 800° C., (2) anodizing in an electrolytic bath, or (3) coating with a ceramic composition containing an oxidizing agent and heating briefly to the curing temperature of the ceramic. The inventor has discovered that by such means, an oxidized surface may be formed on the plating which provides a suitable base for the subsequent application of ceramic C or vitreous insulating coatings. The adherence of such coatings to the oxidized surface of plating metal or alloy is excellent, whereas it has been found that vitreous coatings show little or no adherence to such metals or alloys which are not oxidized. Under certain conditions with some ceramic formulations, sufficient oxidation of the plating metal or alloy occurs even without the presence of an oxidizing agent in the ceramic formulation. High temperatures and long curing times promote natural oxidation of the plating surface. It is desirable to roughen the plating surface by sandblasting, acid etching, or other means in order to further promote adherence to the vitreous coating.

The exact formulation of the ceramic coating may vary over a wide range of composition. Examples of glassy bonding agents are: lead borate, lead silicate, and combinations of the two, and mixtures of sodium, calcium, and potassium silicates. Refractory components mixed with the bonding agent may be, for example, aluminum oxide, titanium oxide, zirconium oxide, beryllium oxide, finely ground natural and synthetic micas, or finely chopped fibers of quartz, aluminum silicate, potassium titanate, or asbestos. These and other refractory materials may be admixed with glassy bonding agents to obtain ceramic coatings having a variety of properties. The coating may be applied by known methods such as drag coating or electrophoresis.

Other methods of bonding inorganic insulating coatings to a chromium, rhenium, or iron base may be employed within the scope of the invention. For example, a fluoride coating may be formed on such metals or alloys thereof by heating in fluorine, hydrogen fluoride, or fluorocarbon gas. Alternatively, the wire coated with chromium, rhenium or iron, or alloys thereof, may be made the anode in a non-aqueous electrolytic bath containing hydrogen fluoride. The fluoride layer so formed is further diffused into the metal coating by heating at elevated temperature, yielding a flexible, adherent, insulating coating.

The method of the invention is applicable not only to wire but also to other types of conductors such as

copper or silver tubing and foil, which are plated with chromium, rhenium, iron or alloys thereof and insulated as described.

It has been found that conductors prepared in accordance with the invention are either completely free from, or exhibit a relatively small degree of the diffusion effects which cause a permanent increase in the resistance of clad wires hitherto offered for high temperature service. Copper plated with either chromium or rhenium, and silver plated with chromium, show negligible change in resistance upon heating for 2,000 hours in argon at 600° C. Copper and silver, iron plated, show only a small increase in resistance when heated under similar conditions. By way of contrast, the resistance of commercial nickel clad copper wire was found to increase 350 percent in the same test. Other types of commercial clad and plated wires, such as copper clad with Inconel or stainless steel also show large increases in resistance upon prolonged heating in an inert atmosphere.

While there is described herein methods and means of construction of a ceramic coated or inorganic material coated conductor forming a wire for use in, for example, a magnet coil it should be clearly understood that these examples in no way limit the scope of the invention. It is apparent that the methods and structures disclosed herein are applicable to other uses particularly where it is

desirable to insulate a conductor with a thin coating of temperature resistant insulation. The scope of the invention is set forth in the accompanying claims.

What is claimed is:

1. An insulated conductor comprising a body of conductive material selected from the group consisting of copper and silver, a first layer covering said body, said first layer being a metal selected from the group consisting of chromium, rhenium and iron and alloys thereof, and a second layer covering said first layer, said second layer comprising particles of refractory material.

2. An insulated conductor as set forth in claim 1 wherein the second layer is a vitreous material.

3. An insulated conductor comprising a core of copper, a layer of rhenium on said core, and a second layer covering said rhenium layer and comprising particles of refractory material.

4. An insulated conductor comprising a core of silver, a layer of chromium on said core, and a second layer covering said chromium layer and comprising particles of refractory material.

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