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**CERAMIC-COATED ELECTRICALLY-CONDUCTIVE WIRE AND METHOD OF MAKING SAME**

Hollis S. Saunders, Fort Wayne, and Robert W. Gehring, Grabill, Ind., assignors to Phelps Dodge Copper Products Corporation, New York, N.Y., a corporation of Delaware

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This invention relates to insulated electrically-conductive wire of the ceramic-coated type and more particularly to an improved wire of this type and a novel method of making the same.

The present invention is applicable to lead wire, resistance wire, magnet wire, and the like, but for the purpose of illustration will be described in connection with magnet wire.

Magnet wire must be insulated adequately to prevent shorting between adjacent turns of the wire and also to prevent electrical contact between the wire and any adjacent conductive part, such as a magnetic core on which the wire is placed. Moreover, since space is usually an important factor in electrical equipment, the insulation of the magnet wire should occupy as little space as possible. At the same time, the insulation should have good dielectric strength in view of the high voltages often applied across such wires. A further factor is the extent to which the magnet wire is "worked" after the insulation has been applied. For example, winding the wire into a coil will often impose considerable stress on the insulation and tend to abrade and crack it and also to pull it away from the wire. Still another factor is that the electrical apparatus into which the wire is assembled may be subjected to temperature extremes, both high and low, which the wire insulation must be capable of withstanding.

In other words, the magnet wire insulation should have high degrees of flexibility and toughness, strong adhesion to the wire even when the wire is bent considerably, high dielectric strength, the qualities of hardness and resistance to abrasion, and the ability to withstand temperature extremes.

It is well known that ceramic or refractory dielectric materials, as commonly applied to magnet wire, give excellent dielectric properties but have poor flexibility and poor adhesion to the wire. As a result, these materials have resulted in breakage or weakening of the dielectric coating in the normal use of the magnet wire.

Attempts have been made to overcome these disadvantages in mechanical properties of ceramic insulation for wire, as by combining the ceramic or refractory coating with an outer coating of a resinous material. It has also been proposed to improve the mechanical properties of ceramic-coated wire by coating the wire with a liquid suspension of a composition consisting of a frit of refractory material (such as a mixture of zinc, cobalt and silicon oxides) in a minor proportion and a major proportion of a flux comprising a mixture of lead borate and lead borosilicate; and then fire the coated suspension under such time and temperature conditions that the coating is completely fused on the wire. By such complete fusion, the final coating is in a glassy phase, except possibly for slight crystallization at the surface. Thus, according to Fraher Patent No. 2,907,665, dated October 6, 1959, the coated suspension is fired at a temperature of 1100° F. to 1350° F. for a period of about 20 minutes; and even such slight crystallization at the surface which would result from incorporating titanium dioxide into the coating was considered undesirable.

Insofar as we are aware, the various prior proposals for improving ceramic-coated wire have not overcome satisfactorily the problems of poor flexibility and poor adhesion encountered with such wire.

The principal object of the present invention is to provide a magnet wire insulated by a ceramic coating which retains essentially all the desired properties of such coatings but has substantially greater flexibility and adhesion to the wire than has been attained heretofore with such coatings.

We have discovered that a ceramic-coated magnet wire of exceptional flexibility can be obtained by providing the wire with semi-vitreous ceramic coatings separately fired on the conductor and containing in their final condition substantial proportions of both glassy and crystalline phases. More particularly, a magnet wire made according to the invention comprises an elongated oxidation-resistant electrical conductor, and multiple ceramic coatings fired separately in place on the conductor and each consisting essentially of substantial proportions of both glassy and crystalline phases which are the product of partial fusion of a mixture of (a) a frit selected from the group consisting of lead borate, lead silico-borate, lead silicate, barium boro-silicate, barium-alumino-silico-borate, and mixtures thereof, and (b) a refractory dielectric material, the latter constituting a minor part but at least 5 parts (by weight) of the mixture of (a) and (b). When the components of this mixture are fused together on the conductor, the refractory material has a limited solubility in the glassy phase formed from the melted frit, so that only part of the refractory material is dissolved. Thus, as a result of the remaining undissolved refractory material, the final coating or ceramic system has a substantial crystalline phase dispersed through the glassy phase as evidenced by the X-ray diffraction pattern of the fired coating.

As will be understood by those skilled in the art, the frit is obtained by melting one of the borates or silicates selected from the above-mentioned group, or a combination of them, to form molten glass which is then suddenly cooled (as by quenching in water or between water-cooled rolls) to form glass made up of small friable particles. The frit should be essentially alkali-free to retain fully its excellent electrical insulating property.

The refractory dielectric material may be any of the commonly known ones, such as chromium oxide, boron nitride, titanium dioxide, zirconium dioxide, silicon dioxide, nickel oxide, mica (either natural or man-made), aluminum oxide, alumina-silicate, and other similar refractory compounds or mixtures thereof.

The excellent adhesion of this ceramic coating to the metal substrate is obtained through the solution of the metal oxide, formed in the initial stages of curing, by the glassy phase, to form a saturated interfacial layer of this metal oxide in the glassy phase at the metal-ceramic interface. The superior flexibility of this system is obtained by the combination of the glassy and crystalline phases of the coating. This flexibility is considerably less if the combination of the frit and refractory material does not form separate glassy and crystalline phases, that is, if the refractory material is completely dissolved by the glassy phase to form a vitreous or glassy system. If the content of the refractory material in the frit-refractory mixture is less than the aforesaid minimum of 5%, the desired flexibility is not attained; and if this content is over 30%, the desired strong adhesion of the ceramic to the wire is not attained.

For best results, each coating of the partially fused mixture should have a thickness of 0.05 to 0.25 mil. Also, the preferred embodiment of the new wire comprises a layer of a linear thermoplastic polymer coated on the