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SURFACE-MOUNTED ELECTRICAL RESISTANCE STRUCTURE AND METHOD FOR PRODUCING SAME

Filed April 9, 1962

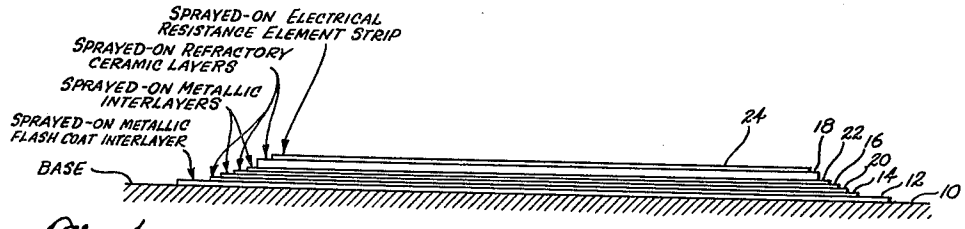


Fig. 1.

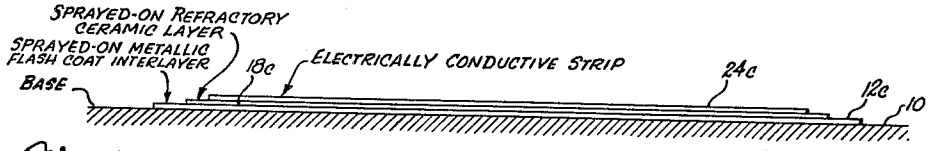


Fig. 2.

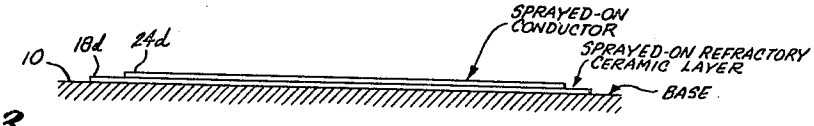


Fig. 3.

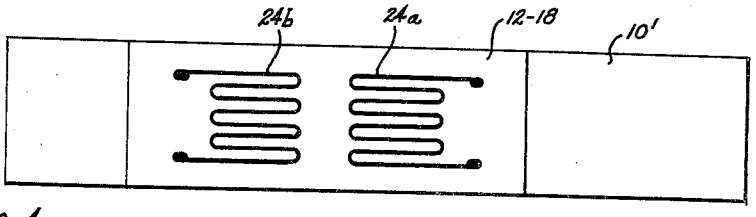


Fig. 4.

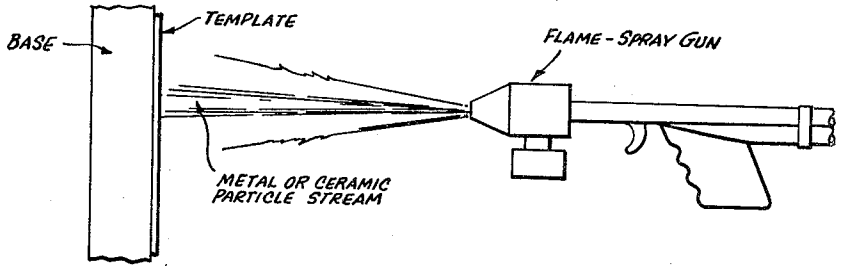


Fig. 5.

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SURFACE-MOUNTED ELECTRICAL RESISTANCE STRUCTURE AND METHOD FOR PRODUCING SAME

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This invention relates to improvements in surface-mounted electrical resistance devices for operating in very high temperature environments or for operating in environments undergoing wide temperature changes. Applications for devices of this nature include strain gauges, resistance thermometers, electrical resistance or conductance elements for general use, and others. The novel concepts of the invention are herein illustratively described by reference to the presently preferred embodiments thereof; however, it will be recognized that certain modifications and changes therein with respect to details may be made without departing from the underlying essentials involved.

A broad object hereof is to provide durable and reliable electrical resistance elements and the like of a type formed upon and adhered to a base surface by an insulating medium capable of withstanding extreme conditions of temperature, temperature variation, physical strain, flexure and abrasion. A related object is to achieve temperature stability and low drift in such devices.

A related object is to bond such elements with an insulating medium able to maintain a high insulation coefficient at very high operating temperatures where conventional bonding insulations tend to become excessively conductive.

A further object is to provide an insulating and bonding technique achieving the above purposes with refractory ceramic materials as the insulation.

A further object of this invention is to provide an improved strain gauge, resistance thermometer element, or similar device of the surface-mounted type which is readily applied by known and readily available techniques and materials, and which may be applied with any desired configuration and to surfaces of practically any shape or contour.

A further object of this invention is to provide electrical sensing devices having any selected resistance value within a convenient range, such as from a few ohms or less to 100 ohms or more, and having the capability of carrying relatively heavy current without overheating. As a result, associated electric circuit systems in which these devices are connected may be of simple, noncritical design.

In accordance with this invention as presently disclosed, components of the resistance structure are all applied by a "flame-spraying" technique. The term "flange-spraying" as used herein is intended to have a generic connotation including any of various commercially known or feasible systems by which the materials are deposited on a surface in molten or plastic particulate form at high temperatures and at high velocities. One suitable flame-spraying method is the Thermo Spray method of Metco, Inc.; another is the Rokide process of the Norton Co.; still another the Flame Plating process of the Linde Company. In one case, metallic material to be deposited is fed through a gun by an automatic feed mechanism into an oxyacetylene flame where it becomes softened or plasticized. A blast of compressed air atomizes the particles into a fine spray and propels them out of the gun against the structure or surface to receive them. In another process, the base materials are initially powdered and may include a virtually endless variety of metals, alloys, ceramics cermets, and combinations of materials. Still another process is the so-called "Plasma Jet" process

which uses a torch to produce a controlled high-velocity inert gas stream at extremely high temperatures (i.e., in the range between 12,000° F. and 30,000° F.). The hot gases melt and accelerate to high velocity and refractory materials whether in a powder or solid form.

A particular feature of importance herein is the achievement of high strength and mechanical stability in the total structure, though ceramics are used in the insulation, by a process of lamination. According to this process, a flash coating is first flame-sprayed on the base surface whereupon one or more refractory ceramic coatings are successively flame-sprayed over the flash coating with flame-sprayed interlayers of metallic material interposed between the successive ceramic layers. Finally, the resistance strip itself is flame-sprayed on the outermost ceramic layer, which is preferably made thicker than underlying ceramic layers. By choosing a flash coating material and interlayer metal material which have a temperature expansion coefficient intermediate that of the base material and of the ceramic material, the desired strength, stability and other advantageous characteristics mentioned above are achieved in the total structure and there is minimal tendency for fracture of the refractory ceramic material or failure of its bond to the base due to dimensional changes of the latter accompanying wide variations of temperature. In a strain gauge, for example, it is possible with this improved system to achieve temperature stability and acceptable accuracy to temperatures as high as 2000° F. more or less.

Fusion of the conductive layer by heating the structure to a high temperature in a hydrogen (reducing) atmosphere imparts still greater toughness and tensile strength to the resistance structure and further minimizes drift of resistance value over a period of time.

For certain limited applications, a single refractory ceramic layer may be flame-sprayed directly upon the base surface and may comprise the sole supporting and insulating layer for the conductive strip flame-sprayed directly on such layer. However, for most applications, especially where high temperatures or wide variations in temperature are involved, a laminar insulation structure is essential to achievement of the desired characateristics of the device.

These and other features, objects and advantages of the invention will become more fully evident from the following description thereof by reference to the accompanying drawings.

FIGURE 1 is an edge view of an electrical resistance structure applied to a base in accordance with one embodiment of the invention.

FIGURE 2 is a similar view showing a modified embodiment.

FIGURE 3 is a similar view showing still another modified embodiment.

FIGURE 4 is a face view of a strain gauge structure applied to a base strip according to the invention.

FIGURE 5 is an operating view showing use of flame spray equipment in manufacturing resistance structures according to this invention.

In order to satisfy the increasing requirement for strain gauges, resistance thermometers and other resistance devices capable of operating under extremes of temperature and strain, the present invention utilizes a technique of depositing both the resistance element material and its insulation medium by a flame-spraying technique wherein high-temperature particles of material are projected at high velocity in a plastic or molten state onto the supporting surface. It is found that extraordinary temperature stability and the other attributes mentioned above are achieved when this technique is used apparently because the material deposited has been exposed or cycled to an extremely high temperature in the deposit-

ing operation itself. Enhancement of temperature stability can be achieved by the further expedient of fusing the deposits in a hydrogen reduction atmosphere at high temperature so as to increase the ductility and amorphous character of the coating materials by removing detrimental oxide contamination.

In the presently preferred embodiment as shown in FIGURE 1, the supporting base 10 is assumed to be of metal and is part of an element or structure subjected to extremely high temperatures or to a wide variation of temperature. However, it will be recognized that, while this invention rises to the challenge of extreme environmental conditions as previously mentioned, its usefulness is not necessarily confined thereto.

Upon the base 10 there is first deposited by a flame-spraying technique a flash coating or underlayer 12 of metallic substance which is to carry the remainder of the insulation structure and the surmounted electrical resistance strip to be described. This flash coating is of a material which exhibits a temperature expansion coefficient intermediate that of the base 10 and of the refractory ceramic layer 14 flame-sprayed on the layer 12. In this embodiment additional refractory ceramic layers 16 and 18 are flame-sprayed successively over the layer 14 and are separated by flame-sprayed interlayers of metallic material, 20 and 22, from the layer 14 and from each other, respectively. Preferably the outer ceramic layer 18 is materially thicker than the underlying ceramic layers 14 and 16. Finally, the electrically conductive strip 24, of any desired configuration, is flame-sprayed on the outermost refractory ceramic layer 18.

One suitable electrical resistance strip configuration is shown in FIGURE 4 wherein the resistance element 24*a* comprises a sinuous conductor, companion to a similar conductor 24*b* mounted upon the same base 10′ and insulation laminate 12–18, as shown. These elements 24*a* and 24*b* may represent a pair of strain gauge resistance elements mounted on a test specimen comprising the base 10′. Alternatively, they may comprise the resistance elements of a resistance thermometer or other electrical device.

FIGURE 5 depicts a suitable flame-spray gun in operation directing a stream of plasticized or molten particles against a base. A template superimposed on the base in the path of the stream of particles insures proper masking of the base surface surface in areas other than those to be coated. The process is a direct and rapid one which, depending upon the choice of materials and techniques used, may be worked with practically any metal, metal alloy, ceramic, or cermet, as required for different applications of the improved electrical resistance structures.

In a representative case, assuming the base material to comprise a metal alloy having a temperature expansion coefficient of the order of 8 or 9, the refractory ceramic material used in the layers 14, 16 and 18 will be aluminum oxide (Al_2O_3) while the flash coating 12 and the interlayer coatings 20 and 22 are of nickel-chromium alloy, or molybdenum. Either of these coatings exhibit a temperature expansion coefficient of the order of 5 or 6, which is generally intermediate the value of about 10 for the base 10 and that of about 4 for aluminum oxide.

It is desirable for the usual reasons in the case of a strain gauge to maintain a composite structure which is relatively shallow, and in which, accordingly, the individual layers of the composite or assembly are microscopically thin. The term "microscopically thin" as used here is intended to cover thicknesses for the layers 12, 14, 16, 18, 20 and 22 which usually should not exceed a few thousandths of an inch thickness individually. For example, the flash coating may have a thickness of 0.002 of an inch, and each of the other coatings may have a thickness of 0.003 of an inch, except the outermost coating. As much as possible of the total requisite insulation thickness is relegated to this outer coating in order to enhance the advantages of the lamination method. Typically this outer coating may be of the order of 0.007 of an inch in thickness. The conductive resistance strip in a typical strain gauge application may have a thickness of the order of 0.003 of an inch. The term "shallow" as used here is intended to cover composites or assemblies made up of layers of such thicknesses, or of the order thereof, and ranging in number from that shown in FIGURE 2 to that shown in FIGURE 1. The latter limit is a matter of balancing the risk of leakage current flow against total thickness of the composite.

If desired, the interlayers could be of metals other than molybdenum or nickel-chromium alloy, although the latter is desirable in cases where temperature stability is needed. Care should be exercised in choosing metals which cooperatively do not exhibit a bimetal bending effect. Thus, it is desirable to employ interlayer material and flash coating material which have approximately the same temperature expansion coefficient as that of the resistance strip material so as to minimize internal strains in the gauge structure due to temperature changes.

In order to avoid leakage current flow between the metal layers in the laminar structure, the refractory ceramic deposits should not be much thinner than the values named above. Therefore, in order to minimize or limit the total thickness of the composite laminate, the number of layers used must be limited. The arrangement shown in FIGURE 1 represents about the maximum, and indeed it is usually the optimum number of layers which should be used for most applications considering the derivation of benefits from the laminar arrangement of insulation layers.

In FIGURE 2 the electrically conductive strip or resistance element 24*c* is flame-sprayed on a single refractory ceramic layer 18*c* which in turn is flame-sprayed on the flash coating 12C. The latter, deposited directly on the surface of the base 10, affords a means to prevent excessive strain in the refractory ceramic layer 18*c* as a result of temperature variations.

In the embodiment shown in FIGURE 3, the flash coating is dispensed with and the resistance structure is achieved by depositing the refractory ceramic coating 18*d* directly on the base 10 and by depositing the conductive strip 24*d* directly on the layer 18*d*. However, even though these layers are deposited by a flame spraying technique, the composite structure of FIGURE 3 is not nearly as effective as that in FIGURE 2, which, however, is not nearly as satisfactory as that in FIGURE 1 from the standpoint of the various objectives set forth hereinabove.

Of the various refractory ceramic materials tried, Al_2O_3 proved to be most satisfactory. ZrO, MgO, BeO and ThO represent other specific examples. However, the list of refractory ceramics which may be used with varying degrees of success runs into the hundreds. Various aluminates, silicates, nitrides and others. The considerations of high tensile strength and electrical insulation factor are of paramount importance in these instruments; however, for many applications, particularly high temperature strain gauges, the necessary degree of toughness or tensile strength, temperature stability, low drift characteristics and high insulation qualities at high temperatures are achieved, even with aluminum oxide as the refractory ceramic, only by employing the novel laminar construction employing a plurality of refractory ceramic layers separated by metallic interlayers.

The concept of flame-spraying the various layers onto their respective supporting surfaces is essential to these instruments. This flame-spraying may be carried out in the atmosphere without difficulty. However, when added ductility and strength are needed, heating to high temperature in a reducing atmosphere of hydrogen is em-

ployed in order to reduce the oxides present and produce a smooth and amorphous conductive layer. Such fusion should be carried out at a temperature of the order of 2000° F., which is just the softening point of nickel-chromium alloy, at which the particles run together and become thoroughly embedded in the underlying coating. If a materially higher temperature is reached, such as of the order of 2200° F. or 2300° F., the metal tends to ball up instead of run. Other metals or metal alloys will fuse at a different temperature.

A further embodiment is the use of plasma spray equipment in forming strain gauges and other resistance elements. Since the plasma spray uses inert gas such as argon, helium, hydrogen, nitrogen or others as opposed to oxygen in the oxyacetylene spray equipment, then subsequent oxide decontamination in a hydrogen reducing atmosphere is not necessary. Also, with the extremely high temperatures available in a plasma jet, it is possible to fuse the strain gauge resistance elements during the forming of the strain gauge without subsequently subjecting the gauges to a fusing temperature in a hydrogen reducing atmosphere. However, care should be exercised to prevent the presence of any oxidizing atmosphere when using the plasma spray in order not to cause oxide contamination during spraying of the resistance elements. Also denser ceramic coatings are possible because of greater deposit efficiency of the plasma spray.

The important function of the precoat or flash coat applied to the base surface, using nickel-chromium alloy, molybdenum, or other suitable metal having the desired relative temperature expansion coefficient, is to cause the flame-sprayed refractor ceramic to stick to its supporting surface. Whereas it will not stick readily to metals which have a widely different temperature expansion coefficient than the ceramic, it will stick to a metal layer which has a coefficient of intermediate value. The flash coat acts as a thermal stabilizer preventing the oxides by which the refractory ceramic is bonded to its supporting surface from popping off due to changes of temperature.

If desired, certain additives may be mixed with the aluminum oxide or other refractory ceramic layer during spraying in order to improve the strain characteristics of the ceramic coatings. For example, a small percentage of glass rock (silica dioxide) or glass frit tends to maintain a more stable and repeatable strain characteristic as well as to enhance the bonding quality of the coating for extremely high-temperature applications for which the instrument is subjected to fusion at high temperatures in a reducing atmosphere.

Another feature worthy of note herein is the concept of not only laminating the insular structure of the gauge but of graduating the thickness of the ceramic coatings. As shown in FIGURE 1, the outer refractory ceramic coating 18 is materially thicker than the inner ceramic coatings 14 and 16. This thickness relationship further assists in adding to the tensile strength of the composite structure and to the minimizing of coating damage due to drastically unequal coefficients of expansion of the base material and of the coating materials.

The choice of metal for the electrical resistance element depends upon the application. Nickel-chromium alloy has the characteristic, desirable for strain gauges, of substantially constant resistance throughout a wide range of temperature change while sensitively changing its resistance in response to variations in strain. Other materials would be used for temperature sensors, which would be sensitive to temperature only and relatively insensitive to strain. The alloy Nilvar is one example.

If desired the successive layers or coatings can be graduated with each other by employing two spray guns one of which is progressively throttled to decrease its output while the other is progressively opened to increase its output. Thus, there will not be a sharp line of demarcation between layers but a definite blending of metallic and ceramic substances, with "cermet" substance formed in the interlayer region. Such an arrangement further augments the above-mentioned desirable characteristics of these laminated gauge or resistance structures.

After completion of the layer deposits a protective ceramic overlayer may be flame-sprayed over the entire unit and beyond its edges onto the base surface in order to seal it against damage and the effects of moisture condensation and the like.

These and other aspects of the invention will be evident to those skilled in this art on the basis of the foregoing disclosure of the preferred embodiments and practices thereof.

I claim as my invention:

1. In combination, a solid metallic base for use in high temperature environments, and an assembly of superposed solid, alternately metallic and ceramic layers, between 3 and 7 in number, inclusive, adhering thereon and consisting essentially of a metallic flash coat adhering directly to the base and having a thickness of about 0.002 of an inch, an electrically insulative refractory ceramic coat adhering directly to the opposite face of the flash coat and having a thickness of about 0.003–0.007 of an inch, and an electrically conductive resistance metal strip having a thickness of about 0.003 of an inch, overlying and adhered to the opposite face of the ceramic coat, and said flash coat having a temperature expansion coefficient intermediate those of the base metal and the refractory ceramic.

2. The combination according to claim 1 wherein the individual layers consist of heat fusible substances and have the attributes of coatings solidified in situ from a high temperature molten state.

3. The combination according to claim 2 wherein the substances are flame-sprayable and the layers have the attributes of coatings deposited by high velocity thermal spraying techniques.

4. The combination according to claim 3 wherein the layers also have the attributes of coatings heated to fusion temperatures in a reductive atmosphere.

5. The combination according to claim 1 wherein the resistance metal strip is directly adhered to the opposite face of the ceramic coat.

6. The combination according to claim 1 wherein the refractory ceramic is aluminum oxide, and the metal of the flash coat is selected from the group consisting of molybdenum and nickel-chromium alloy.

7. A combination according to claim 1 wherein the resistance metal strip is adhered to the opposite face of the ceramic coat through the medium of a subassembly of superposed solid, alternately metallic and ceramic interlayers, between 2 and 4 in number, inclusive, interposed between the ceramic coat and the strip, the undermost of which interlayers is metallic and the outermost of which is ceramic, and each metallic of which interlayers has a thickness of about 0.002 of an inch and each ceramic of which interlayers has a thickness of about 0.003–0.007 of an inch, the metallic interlayer having a temperature expansion coefficient intermediate those of the base metal and the refractory ceramic.

8. The combination according to claim 7 wherein the ceramic interlayers are increasingly thicker in the direction transverse the subassembly relatively from the ceramic coat to the resistance metal strip.

9. The combination according to claim 7 wherein the metallic interlayers and the flash coat have approximately the same temperature expansion coefficient as that of the resistance metal strip.

10. A method of forming an insulated high temperature electrical resistance element on a solid metallic base structure, comprising forming an assembly of superposed solid, alternately metallic and ceramic coatings, between 3 and 7 in number, inclusive, on the base structure, by employing flame sprayable metallic and ceramic substances for the coatings and depositing the coatings in a

high temperature molten state by a high velocity thermal spraying technique, the coatings being applied and solidified in situ from such state, firstly, as a metallic flash coat adhering directly to the base structure and having a thickness of about 0.002 of an inch, secondly, as an electrically insulative refractory ceramic coat adhering directly to the opposite face of the flash coat and having a thickness of about 0.003–0.007 of an inch, and thirdly, as an electrically conductive resistance metal strip having a thickness of about 0.003 of an inch, overlying and adhered to the opposite face of the ceramic coat, the metal of the flash coat being selected to have a temperature expansion coefficient intermediate those of the base metal and the refractory ceramic.

11. The method according to claim **10** wherein the resistance metal strip is adhered to the opposite face of the ceramic coat through the medium of a subassembly of superposed solid, alternately metallic and ceramic intercoatings, between 2 and 4 in number, inclusive, interposed between the ceramic coat and the strip, and formed by employing flame sprayable metallic and ceramic substances for the intercoatings and depositing the intercoatings in a high temperature molten state by a high velocity thermal spraying technique, the undermost of the intercoatings being metallic and the outermost being ceramic, the metallic of the intercoatings having a thickness of about 0.002 of an inch and the ceramic of the intercoatings having a thickness of about 0.003–0.007 of an inch, and the metallic intercoating having a temperature expansion coefficient intermediate those of the base metal and the refractory ceramic.

12. The method according to claim **10** wherein the resistance metal strip is directly adhered to the opposite face of the ceramic coat.

13. The method according to claim **10** wherein the assembly is subsequently heated to fusion temperatures in a reductive atmosphere.

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