

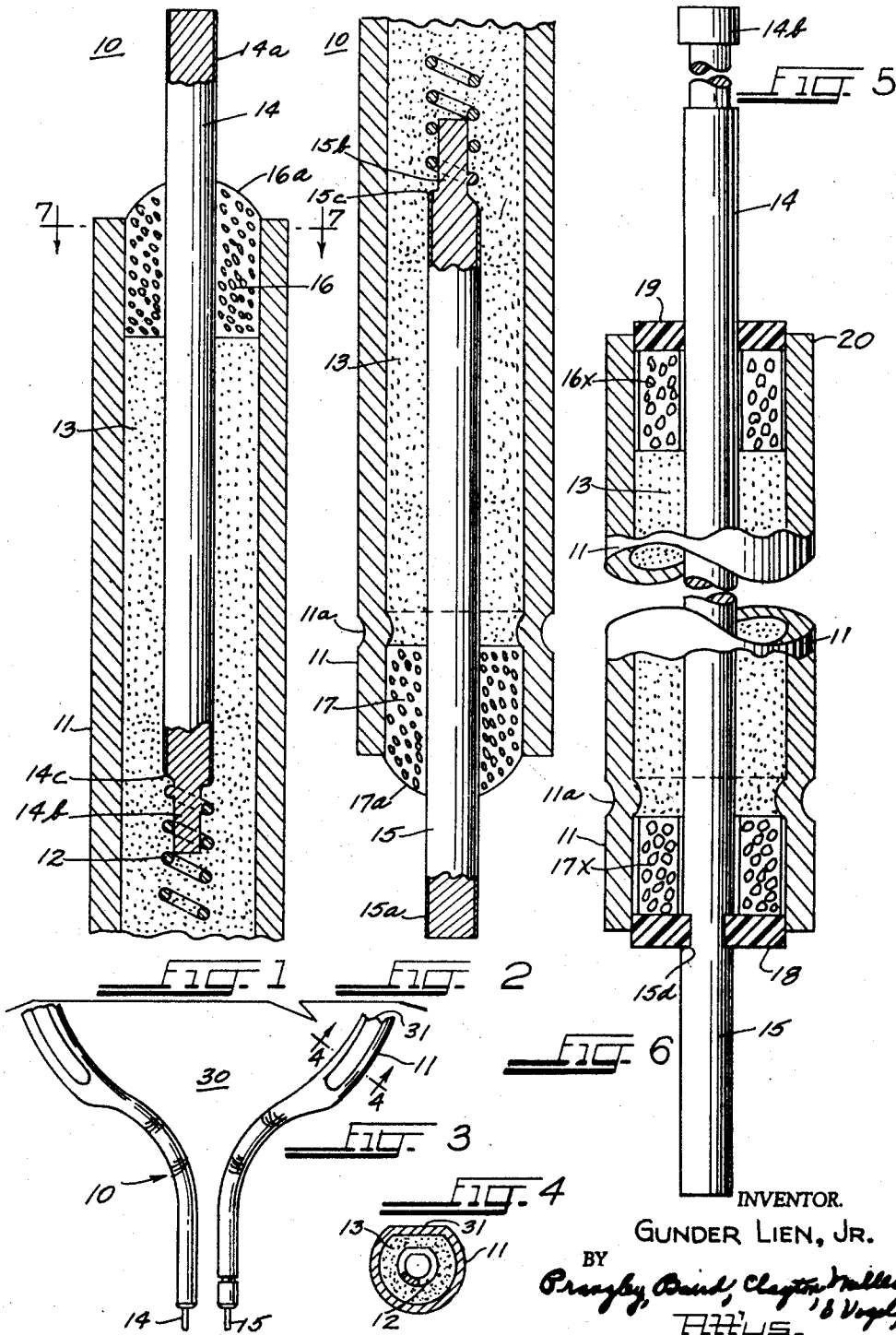
Nov. 29, 1960

G. LIEN, JR.
SHEATHED ELECTRIC HEATING UNITS AND
METHODS OF MAKING THE SAME

2,962,684

Filed Nov. 12, 1958

2 Sheets-Sheet 1



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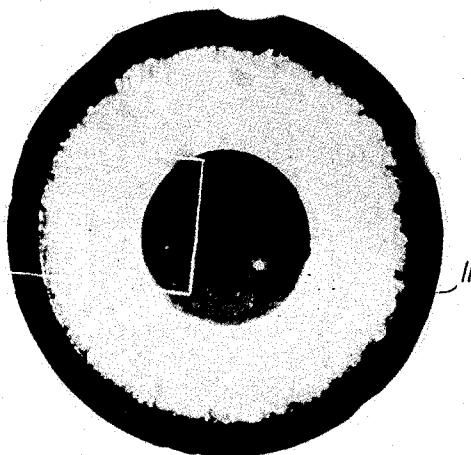
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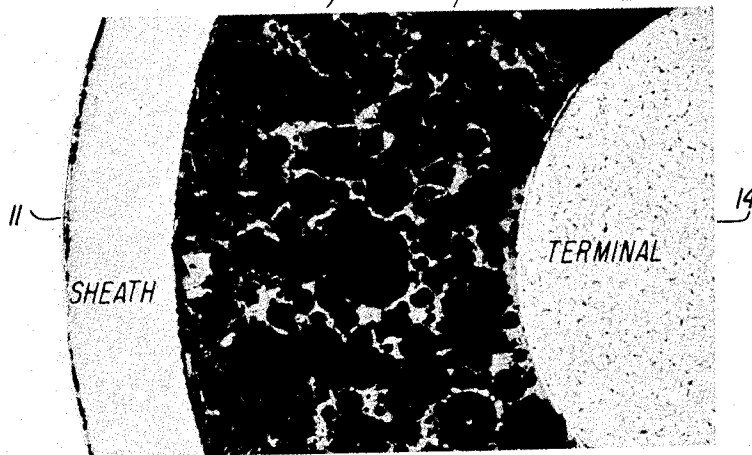
Fig. 7



ENLARGEMENT-15X

KAOLIN	28%
SILICA	27%
ZIRCONIUM SILICATE	36%
CALCIUM CARBONATE	3%
BORAX	5%
SODIUM SILICATE	1%

Fig. 8



ENLARGEMENT- 50X

INVENTOR

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2,962,684

**SHEATHED ELECTRIC HEATING UNITS AND
METHODS OF MAKING THE SAME****Gunder Lien, Jr., Wheaton, Ill., assignor to General Electric Company, a corporation of New York****Filed Nov. 12, 1958, Ser. No. 773,217****16 Claims. (Cl. 338—243)**

The present invention relates to sheathed electric heating units and methods of making the same. This application is a continuation-in-part of the copending application of Gunder Lien, Jr., Serial No. 685,728, filed September 23, 1957, now abandoned.

Heretofore in the design of electric heating units of the sheathed resistance conductor type, emphasis has been laid upon producing truly hermetic seals in the opposite ends of the sheath and surrounding terminals respectively projecting therefrom to the exterior, with the view of eliminating totally the entrance of air and moisture into the opposite ends of the sheath; and in order to effect this result glass seals have been extensively used.

It has now been discovered that it is undesirable to provide such hermetic seals in the opposite ends of a heating unit of the sheathed resistance conductor type, but rather it is advantageous to provide seals therein that actually accommodate controlled breathing of air between the interior of the sheath and the atmosphere, thereby reducing pressure damage to the seals, and inducing a longer useful life of the heating unit.

More particularly, it will be apparent that when the resistance conductor of a heating unit of this type is energized, the temperature thereof, as well as that of the embedding compacted mass of heat-conducting and electrical-insulating material, increases very rapidly from the ambient temperature, with the result that the temperature of the air permeating the compacted mass mentioned likewise increases very rapidly, so that the pressure thereof rapidly increases from substantially atmospheric pressure to a relatively high pressure, whereby there is the danger of failure of at least one of the seals at one end of the sheath. In the usual case, and after some use of the heating unit in service, the high pressure mentioned may cause failure of at least one of the glass seals, thereby destroying the hermetic character thereof; whereby thereafter, the high pressure mentioned is slowly relieved to the atmosphere by uncontrolled leakage through the damaged seal, and usually at a relatively low rate; and subsequently, when the resistance conductor of the heating unit is deenergized, reverse effects are produced, whereby the damaged seal leaks air at an exceedingly low rate from the exterior back into the adjacent one end of the sheath in order very slowly to relieve the subatmospheric pressure condition therein.

It is believed that this alternate relatively high pressure condition and subatmospheric pressure condition within the sheath materially shortens the useful life expectancy of the heating unit, when it has a damaged seal; and it is surmised that one of the factors that is very deleterious in this regard is the vaporization of the metal of the resistance conductors, while it is at an elevated temperature and during the subatmospheric pressure condition in the sheath. In any case, it has now been discovered that an extended useful life can be obtained in a sheathed electric heating unit by substituting for the usual hermetic seals in the opposite ends of the sheath, vitreous seals that are so constructed and arranged that they accom-

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modate controlled breathing of air for the purpose of minimizing the difference between the pressure of the air within the sheath and atmospheric pressure, while effectively sealing the ends of the sheath against the entry of foreign materials thereinto and against the loss of the dense mass of heat-conducting and electrical-insulating material embedding the resistance conductor therein, and providing optimum insulation between the sheath and the electric terminal extending therefrom.

Accordingly, it is an object of the present invention to provide in a sheathed electric heating unit, a vitreous cellular seal of the character described.

Another object of the invention is to provide an improved method of making a sheathed electric heating unit, wherein seals of the character described are produced incident to the carrying out of the steps of the method of making the same.

A further object of the invention is to provide a sheathed electric heating unit of improved construction and arrangement, as well as an improved and simplified method of making the same, whereby substantial savings are effected both in the material components of the heating unit and in the manipulative steps involved in the method.

The present invention is predicated upon the aforesaid discovery that the usual life of a sheathed electric heating unit may be desirably prolonged by the utilization of vitreous cellular and porous seals in the opposite ends of the sheath thereof which during the manufacture of the heating units become so constituted that they accommodate controlled breathing of air, while effectively sealing the ends of the sheath against the entry of foreign materials thereinto and against the loss of any of the dense mass of material arranged in embedding relation with respect to the resistance conductor thereof, together with the discovery that these objectives may be achieved by the utilization of a unitary plug of ceramic material arranged in one end of the sheath and intimately bonded to the adjacent inner surface thereof and embedding the adjacent portion of the terminal projecting therethrough and intimately bonded to the adjacent outer surface of the terminal. In the arrangement, the ceramic plug is substantially homogeneous, cellular and porous, and comprises a given composition so that it possesses predetermined characteristics. More particularly, the ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to a predetermined elevated temperature in the approximate temperature range 1900° F. to 2100° F.; while the thus produced vitreous mass is characterized by congealing into a self-supporting substantially homogeneous, but rather cellular and porous, ceramic body upon subsequent cooling thereof below the temperature range mentioned.

Further features of the invention pertain to the particular arrangement of the elements of the sheathed electric heating unit and of the steps of the method of making the same, whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

Figure 1 is a greatly enlarged fragmentary longitudinal sectional view, partly broken away, of the upper end of a sheathed electric heating unit embodying the present invention and made in accordance with the present method;

Fig. 2 is a greatly enlarged fragmentary longitudinal sectional view, partly broken away, of the lower end of the heating unit shown in Fig. 1;

Fig. 3 is a fragmentary plan view at a greatly reduced

scale, of a hotplate produced from the heating unit shown in Figs. 1 and 2;

Fig. 4 is an enlarged lateral sectional view, taken in the direction of the arrows along the line 4—4 of Fig. 3;

Fig. 5 is a greatly enlarged side elevational view, partly broken away, similar to Fig. 1, illustrating certain of the elements arranged at the upper end of the heating unit in the course of manufacture thereof;

Fig. 6 is a greatly enlarged side elevational view, partly broken away, similar to Fig. 2, illustrating certain of the elements arranged at the lower end of the heating unit in the course of manufacture thereof;

Fig. 7 is a lateral sectional view, taken in the direction of the arrows along the line 7—7 in Fig. 1 and representing a photomicrograph of this section of the heating unit at a magnification of 15 $\times$; and

Fig. 8 is a view of a fragmentary portion of Fig. 7, indicated by the rectangle drawn therein, and representing a photomicrograph of this section of the heating unit at a magnification of 50 $\times$.

More particularly, Figs. 7 and 8 were produced respectively from two photomicrographs that were taken of a typical heating unit at the respective magnifications of 15 $\times$ and 50 $\times$. In taking the photomicrograph corresponding to Fig. 7, oblique illumination was employed; and in taking the photomicrograph corresponding to Fig. 8, vertical illumination was employed.

Referring now to Figs. 1 and 2 of the drawings, there is illustrated a sheathed electric heating unit 10 embodying the features of the present invention and made in accordance with the method thereof. More particularly, the upper and lower ends of the heating unit 10 are respectively shown in Figs. 1 and 2; and the heating unit 10 comprises an elongated tubular metal sheath 11 that may be formed of a suitable nickel-chromium-iron alloy and having a substantially cylindrical cross-section, and a helical resistance conductor 12 that may be formed of a suitable nickel-chromium alloy and located substantially centrally within the sheath 11 and embedded in a highly compacted mass of heat-conducting and electrical-insulating material 13 that may essentially comprise magnesia. The resistance conductor 12 is of substantially helical form, and is provided at the opposite upper and lower ends thereof with electrical terminals 14 and 15 projecting from the corresponding ends of the sheath 11.

More particularly, the upper terminal 14 is of substantially rod-like form and may essentially comprise a suitable steel; and preferably the major portion of the outer surface thereof is provided with a thin layer of nickel, indicated at 14a, intimately bonded thereto. The inner or lower end of the terminal 14 is provided with a substantially centrally disposed and forwardly projecting pin-like section 14b that is arranged interiorly of several turns of the upper end of the helical resistance conductor 12 and suitably secured to the extreme upper end of the conductor 12, as indicated at 14c. Similarly, the lower terminal 15 is of substantially rod-like form and may essentially comprise a suitable steel; and preferably the major portion of the outer surface thereof is provided with a thin layer of nickel, indicated at 15a, intimately bonded thereto. The inner or upper end of the terminal 15 is provided with a substantially centrally disposed and forwardly projecting pin-like section 15b that is arranged interiorly of several turns of the lower end of the electrical resistance conductor 12 and suitably secured to the extreme lower end of the conductor 12, as indicated at 15c. Specifically, the opposite ends of the resistance conductor 12 may be secured to the terminals 14 and 15 in accordance with the welding method disclosed in U.S. Patent No. 2,546,315, granted on March 27, 1951, to Sterling A. Oakley. Also, a substantially annular depression or ring 11a is formed in the lower end of the sheath 11 for a purpose more fully explained subsequently.

Further, the heating unit 10 comprises upper and lower seals 16 and 17 respectively arranged in the upper and lower ends of the sheath 11. In the arrangement, the upper terminal 14 is substantially centrally disposed within the upper end of the sheath 11, the inner end of the terminal 14 being embedded in the mass of magnesia 13, and the intermediate portion of the terminal 14 being embedded in the seal 16, and the outer end of the terminal 14 projecting well beyond the upper end of the sheath 11 to accommodate an exterior electrical connection thereto. Similarly, the lower terminal 15 is substantially centrally disposed within the lower end of the sheath 11, the inner end of the terminal 15 being embedded in the mass of magnesia 13, the intermediate portion of the terminal 15 being embedded in the seal 17, and the outer end of the terminal 15 projecting well beyond the lower end of the sheath 11 to accommodate an exterior electrical connection thereto. Each of the seals 16 and 17 essentially comprises a hollow plug of substantially homogeneous, cellular and porous ceramic material; the plug 16 being intimately bonded to the adjacent inner surface of the upper end of the sheath 11 and intimately bonded to the adjacent outer surface of the intermediate portion of the terminal 14, and the extreme outer end thereof being dense, glazed and defining a convex meniscus extending outwardly beyond the adjacent extreme upper end of the sheath 11, as indicated at 16a; and the plug 17 being intimately bonded to the adjacent inner surface of the lower end of the sheath 11 and intimately bonded to the adjacent outer surface of the intermediate portion of the terminal 15, and the extreme outer end thereof being dense, glazed and defining a convex meniscus extending outwardly beyond the adjacent extreme lower end of the sheath 11, as indicated at 17a. In the arrangement, the plug 16 prevents the escape of any of the magnesia 13 from the upper end of the sheath 11 and the meniscus 16a provides additional effective spacing between the terminal 14 and the adjacent extreme upper end of the sheath 11; similarly, the plug 17 prevents the escape of any of the magnesia 13 from the lower end of the sheath 11 and the meniscus 17a provides additional effective spacing between the terminal 15 and the adjacent extreme lower end of the sheath 11.

Each of the plugs 16 and 17 is formed essentially of kaolin and silica and metal silicates and may have the approximate composition, as follows:

	Percent
Kaolin	28
Silica	27
Zirconium silicate	36
Calcium carbonate	3
Borax	5
Sodium silicate	1
	100

This ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to a predetermined elevated temperature in the approximate range 1900° F. to 2100° F.; and the material of the composition set forth has a softening point at approximately 2050° F. This material is further characterized by congealing of the sintered mass upon cooling thereof below the temperature range mentioned into a substantially homogeneous, cellular and porous body of ceramic material.

In view of the foregoing, it will be understood that when the heating unit 10 is energized, the temperature of the resistance conductor 12 rises rapidly from the ambient temperature effecting quick transfer of heat through the dense mass 13 of magnesia to the metal sheath 11 for the useful heating purpose, whereby the temperature of the air contained in the sheath 11 and permeating the dense mass 13 of magnesia is increased rapidly with the

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result that there is a tendency toward a substantial increase in the pressure of the air in the sheath 11, since the rate of expansion of the sheath 11 is only modest. However, in the present construction of the heating unit 10, the (porous) plugs 16 and 17 accommodate a controlled egress of the air therealong from the sheath 11 to the atmosphere so as to prevent an unduly high pressure in the sheath 11. Conversely, when the heating unit 10 is deenergized, reverse effects ensue; whereby there is a rapid contraction of the volume of the air in the sheath 11, with the result that there is a tendency to form a sub-atmospheric pressure therein. However, in the present construction of the heating unit 10, the porous plugs 16 and 17 accommodate a controlled ingress of the air from the atmosphere into the sheath 11 so as to prevent a substantial subatmospheric pressure therein. Accordingly, the plugs 16 and 17 afford controlled breathing of air therethrough in the operation of the heating unit 10 for the purpose of minimizing the difference between the pressure of the atmosphere and the pressure within the sheath 11; which arrangement greatly prolongs the useful life of the heating unit 10. Further, it will be appreciated that the breathing action described takes place substantially along the walls of the plugs 16 and 17, due to the cellular and porous construction thereof.

This construction will best be understood by reference to Figs. 7 and 8, wherein the substantially homogeneous cellular character of the plug 16 is clearly illustrated, and wherein the intimate bonding of the plug 16 at the interfaces with the sheath 11 and with the terminal 15 are clearly shown. More particularly, the controlled breathing of the plug 16 is due to the structural characteristics thereof, establishing the porosity thereof, and does not comprise a leakage path produced by a crack or fissure therethrough or by a complete lack of union of the plug 16 with the sheath 11 or with the terminal 14. Specifically, in Fig. 8, it is clear that the breathing through the plug 16 takes place fundamentally at the interface between the plug 16 and the sheath 11 and at the interface between the plug 16 and the terminal 14, as the voids in the plug 16 at these interfaces are more highly interconnected, establishing the porosity thereof, than throughout the principal body thereof. Further, as indicated in Fig. 8, the nickel layer 14a that is provided on the outer surface of the terminal 14 substantially improves the bonding of the terminal 14 to the plug 16, as it facilitates wetting of the terminal 14 as the ceramic material of the plug 16 is congealed from its vitreous state, as explained more fully hereinafter.

Considering now the method of manufacture of the heating unit 10, and referring particularly to Figs. 5 and 6, the preformed terminals 14 and 15 are welded to the adjacent opposite ends of the helical resistance conductor 12; and a preformed hollow bushing 17X formed of the ceramic material previously described, is placed over the outer end of the lower terminal 15 and retained in place by a combustible washer 18 fitted over the terminal. The location of the ceramic bushing 17X and the washer 18 is insured by the ring-like depression 11a formed in the lower end of the sheath 11, and by the groove 15d in the terminal 15, with which groove 15d the washer 18 interengages. The preformed tubular sheath 11 is then placed in surrounding relation with the subassembly described, the subassembly being threaded through the sheath 11 so that the ceramic bushing 17X is located in the lower end of the sheath 11, as indicated in Fig. 6. At this time, the upper terminal 14 projects from the upper end of the sheath 11; and in passing, it is noted that the upper terminal 14 comprises a knob-like part 14b disposed at the extreme upper end thereof that is adapted to cooperate with the loading machine, as explained more fully below. The combustible washer 18 is preferably formed of a suitable synthetic organic resin, such, for example, as polyethylene or polystyrene.

At this time, the assembly described is transferred to a

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suitable loading machine, such, for example, as that disclosed in U.S. Patent No. 2,316,659, granted on April 13, 1943, to John L. Andrews. In the loading machine, the assembly is retained in a substantially vertical position with the enlarged knob-like part 14b carried by the upper terminal 14 cooperating with the "hook" incorporated in the loading machine and arranged substantially centrally with respect to the upper end of the sheath 11 and projecting therefrom, as illustrated in Fig. 5. At this time, the loading machine is operated so that the magnesia in finely divided or granular form is charged into the upper end of the sheath 11, falling therethrough onto the ceramic bushing 17X and first embedding the inner end of the terminal 15. As the loading machine is operated, the sheath 11 is filled so that the resistance conductor 12 is embedded in the granular material mentioned and ultimately the inner end of the upper terminal 14 is embedded in this granular material. During charging of the insulating material into the sheath 11, the sheath 11 may be vibrated or jarred slightly in order to insure tamping or packing of the finely divided insulating material in the space between the terminals 15 and 14 and the sheath 11 and between the convolutions of the resistance conductor 12 and the sheath 11 and into the core of the helical resistance conductor 12. After the insulating material has been charged into the sheath 11 and tamped in place, filling the spaces mentioned, the assembly is removed from the loading machine. At this time, a hollow void is defined in the extreme upper end of the sheath 11; which hollow void is filled by placing a preformed hollow bushing 16X (identical to the bushing 17X) thereinto. More particularly, the bushing 16X is placed over the outer end of the upper terminal 14, in engagement with the upper end of the mass of insulating material that has been charged into the sheath 11. Also at this time an upper combustible washer 19 (identical to the washer 18) is placed over the extreme outer end of the upper terminal 14 and retained in place by frictional engagement therewith and brought into contact with the extreme upper end of the sheath 11. In the complete assembly thus produced, the bushing 17X serves as a stopper at the lower end of the sheath 11, while the washer 18 serves to prevent the loss of the ceramic material of the bushing 17X from the adjacent lower end of the sheath 11 in the succeeding stage of the method of manufacture. Similarly, the bushing 16X serves as a stopper at the upper end of sheath 11, while the washer 19 serves to prevent the loss of the ceramic material of the bushing 16X from the adjacent upper end of the sheath 11 in the succeeding stage of the method of manufacture.

The completed assembly of Figs. 5 and 6 is then transferred to a rolling machine, such, for example, as that disclosed in U.S. Patent 2,677,172, granted on May 4, 1954, to Sterling A. Oakley, wherein the assembly is subjected to cold working in a plurality of successive cold rolling passes so as substantially to reduce the cross-sectional area of the sheath 11 for the purpose of compacting the finely divided magnesia, so as to produce the highly compacted mass 13 in the finished heating unit 10. More particularly, the rolling machine may comprise a number of substantially elliptical rolling stages, arranged in annular rotated relation between a first cylindrical rolling stage and a last cylindrical rolling stage, so that the sheath 11 is materially reduced in the rolling machine for the purpose explained. As an example: the sheath 11 is initially substantially cylindrical having an outside diameter of approximately 0.263"; and the sheath 11 in the finished heating unit 10 is substantially cylindrical and smooth having an outside diameter of approximately 0.238". Thus in the rolling machine, the outside diameter of the sheath 11 is reduced from 0.263" to 0.238" in the several cold rolling passes effecting a corresponding reduction in the cross-sectional area thereof, this reduction in the initial cross-sectional area of the sheath 11 being about 10% in the present example.

In passing, it is noted that in the operation of the rolling machine disclosed in the Oakley patent mentioned, the assembly is moved through the successive rolling passes effecting the progressive reductions in the cross-sectional area of the sheath 11, as described.

From the rolling machine, the assembly is transferred to an electric annealing furnace provided with a reducing atmosphere, and arranged in a substantially horizontal position therein; whereby the temperature of the assembly is quickly raised from the ambient temperature to a predetermined elevated temperature in the temperature range 1900° F to 2100° F. More particularly, in the present example, the temperature of the assembly is raised from the ambient temperature to an elevated temperature of about 2050° F. in about 8 minutes in the electric furnace; and this elevated temperature of the assembly is held for a short time interval of about 8 minutes; whereupon the assembly is removed from the electric furnace to the air and allowed to cool back to the ambient temperature. As noted, the electric annealing furnace contains a suitable reducing atmosphere which, in the present example, has the approximate composition, as follows:

	Percent
N -----	65
H -----	18
CO -----	11
CO ₂ -----	5
CH ₄ -----	1
	100

In the operation of the rolling machine, the bushing 17X and 16X offer no resistance to the rolls, and are crushed and reduced to finely divided form; however, the respectively associated washers 18 and 19 prevent any substantial escape of the finely divided ceramic material from the respectively associated lower and upper ends of the sheath 11. When the assembly is transferred to the electric annealing furnace, the washers 18 and 19 are quickly destroyed by combustion leaving no carbon deposits upon the respective terminals 15 and 14, and also the two masses of crushed ceramic material of the two bushings 16X and 17X are sintered into two respective unitary vitreous masses disposed in the respective opposite ends of the sheath 11. More particularly, the mass of vitreous material in one end of the sheath 11 expands outwardly producing the meniscus 17a in the plug 17 of the finished heating unit 10; and similarly, the mass of vitreous material in the other end of the sheath 11 expands outwardly producing the meniscus 16a in the plug 16 of the finished heating unit 10. Also the two masses of vitreous material flow into wetting and bonding relation with the adjacent portions of the sheath 11 and with the respective terminals 14 and 15, without flowing from the opposite ends of the sheath 11 sufficiently to produce voids therein. Thereafter, following removal of the assembly from the electric annealing furnace, the two masses of vitreous material congeal into the two respective self-supporting cellular and porous ceramic plugs 16 and 17 intimately bonded to the respective ends of the sheath 11 and intimately bonded to the respective terminals 14 and 15, as previously explained.

Of course, it will be understood that the heat-treatment described not only brings about the formation of the cellular and porous ceramic plugs 16 and 17 in the opposite ends of the sheath 11, but it also effects annealing of the sheath 11 for the purpose of relieving stresses induced therein in the cold working thereof in the preceding rolling operation. Accordingly, upon cooling of the assembly, after removal therefrom from the electric reducing furnace, the heating unit 10 is in a finished state without the performance of further steps thereupon; whereby the finished heating unit 10 may be tested in a conventional

manner and then fashioned into the required heating device.

Recapitulating, the ceramic bushings 16X and 17X have the initial composition set forth, a porosity of about 28%, and a compression strength of about 10,000 lbs./in.². In the rolling machine, each of these bushings is crushed and reduced to a mass of finely divided ceramic material; and in the electric annealing furnace, these two masses are sintered, and upon subsequent cooling, the two cellular and porous ceramic plugs or seals 16 and 17 are produced. Incident to sintering of the two masses of ceramic material in the formation of the plugs 16 and 17, there is an expansion of the masses of compacted material in the general range 25% to 27%; whereby the menisci 16a and 16b are respectively formed upon the extreme outer ends of the plugs 16 and 17; which menisci have glass-like or glazed outer surfaces providing at each meniscus a surface spacing between the adjacent end of the sheath and the corresponding one of the terminals 14 or 15 that is at least $\frac{1}{16}$ ", so as to provide the required electrical insulation along the glazed surface thereof between the parts mentioned. Of course, the plugs 16 and 17 also have the composition set forth, but they are essentially cellular, have only the limited porosity previously noted and are substantially stronger in compression than the corresponding bushings 16X and 17X from which they are respectively produced. Moreover, the plugs 16 and 17 are sufficiently discontinuous in their bonds with the sheath 11 and with the respective terminals 14 and 15 to provide fortuitous passages therealong, and thus effect the limited porosity and the consequent controlled breathing of air at the opposite ends of the sheath 11 for the purpose previously explained.

By way of illustration, in Figs. 3 and 4, there is shown a fragmentary portion of a hotplate 30 that has been formed from the heating unit 10, and more particularly, the heating unit 10 is bent into a substantially annular form in this case with the opposite ends thereof extending first downwardly and then outwardly. After forming the general configuration of the hotplate 30, the upper surface of the sheath 11 is flattened, as indicated at 31, so as to provide a supporting platform for a vessel or other article that is adapted to be heated by the hotplate 30. This flattening of the top surface of the sheath 11, as indicated at 31 in Fig. 4, effects corresponding shaping of the helical resistance conductor 12, as indicated in Fig. 4, and also brings about further compacting of the dense mass 13 of magnesia, so as to eliminate any cracks or fissures produced therein incident to the bending and forming of the hotplate 30.

In view of the foregoing, it is apparent that there has been provided a sheathed electric heating unit of improved construction and arrangement including seals or plugs arranged at the opposite ends thereof and accommodating controlled breathing of air therethrough so as to minimize the difference between atmospheric pressure and the pressure of the air within the sheath in order to bring about a prolonged useful life of the heating unit; and also there has been provided an improved and simplified method of making the heating unit, wherein substantial economies are effected in the manufacture and brought about by the multiple utilization of the ceramic material arranged in the opposite ends of the sheath, initially in the role of stoppers in the production of the assembly, and ultimately in the role of "breathing" seals or plugs in the finished heating unit.

This manufacturing method is particularly advantageous since the ceramic bushings effect early closure of the tubular metal sheath against the entry of foreign materials thereinto. Also, these ceramic bushings are readily crushable in the rolling machine, incident to compacting the granular material within the sheath about the resistance conductor, without damage to the rolls of the machine. Moreover, the resulting finely divided ceramic material, produced incident to the crushing of the bush-

ings, is retained in place in the opposite ends of the sheath during the heat treatment in the annealing furnace; and this crushed material affords the substance out of which the cellular and porous ceramic seals are ultimately produced.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electric heating unit comprising an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end of said sheath, a dense mass of heat-conducting and electrical-insulating material arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, and a porous plug of ceramic material of unitary substantially homogeneous cellular structure arranged in said one end of said sheath and bonded to the adjacent inner surface thereof and embedding the adjacent intermediate portion of said terminal and bonded to the adjacent outer surface thereof, said plug effectively sealing said one end of said sheath against the entry of foreign material thereinto and against the loss of any of said dense mass of material therefrom and establishing controlled breathing of air therethrough into and out of said one end of said sheath for the purpose of minimizing the difference between the pressure of the atmosphere and the pressure within said sheath, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and is characterized by vitrification at elevated temperatures having a softening point in the approximate temperature range 1900° F. to 2100° F.

2. In a sheathed electric heating unit including an electrical resistance conductor and a metal terminal connected thereto and a tubular metal sheath enclosing both said resistance conductor and the inner end and the intermediate portion of said terminal and space therefrom, the combination comprising a porous plug of ceramic material of unitary substantially homogeneous cellular structure arranged in the end of said sheath and bonded to the adjacent inner surface thereof and embedding the intermediate portion of said terminal and bonded to the adjacent outer surface thereof, said plug effectively sealing the end of said sheath against the passage of solid material therethrough and establishing controlled breathing of air therethrough into and out of the end of said sheath, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and is characterized by vitrification at elevated temperatures having a softening point in the approximate temperature range 1900° F. to 2100° F.

3. The sheathed electric heating unit combination set forth in claim 2, wherein the outer surface of the intermediate portion of said terminal carries a thin layer of nickel intimately bonded thereto, so as to facilitate wetting and bonding of said plug thereto and thus to the intermediate portion of said terminal.

4. The sheathed electric heating unit combination set forth in claim 2, wherein the outer end of said plug defines a convex meniscus extending outwardly beyond the adjacent end of said sheath and having a glazed exterior surface.

5. The sheathed electric heating unit combination set forth in claim 2, wherein said plug accommodates said breathing fundamentally along the interfaces thereof

that are respectively bonded to said sheath and to said terminal.

6. In a sheathed electric heating unit including an electrical resistance conductor and a metal terminal connected thereto and a tubular metal sheath enclosing both said resistance conductor and the inner end and the intermediate portion of said terminal and spaced therefrom, the combination comprising a porous plug of ceramic material of unitary substantially homogeneous cellular structure arranged in the end of said sheath and bonded to the adjacent inner surface thereof and embedding the intermediate portion of said terminal and bonded to the adjacent outer surface thereof, said plug effectively sealing the end of said sheath against the passage of solid material therethrough and establishing controlled breathing of air therethrough into and out of the end of said sheath, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and is characterized by vitrification at elevated temperatures having a softening point in the approximate temperature range 1900° F. to 2100° F.

7. In a sheathed electric heating unit including an electrical resistance conductor and a metal terminal connected thereto and a tubular metal sheath enclosing both said resistance conductor and the inner end and the intermediate portion of said terminal and space therefrom, the combination comprising a porous plug of ceramic material of unitary substantially homogeneous cellular structure arranged in the end of said sheath and bonded to the adjacent inner surface thereof and embedding the intermediate portion of said terminal and bonded to the adjacent outer surface thereof, said plug effectively sealing the end of said sheath against the passage of solid material therethrough and establishing controlled breathing of air therethrough into and out of the end of said sheath, wherein said ceramic material includes the following ingredients in the approximate amounts:

	Percent
40 Kaolin	28
Silica	27
Zirconium silicate	36
Calcium carbonate	3
Borax	5
45 Sodium silicate	1
	100

and is characterized by vitrification at elevated temperatures in the approximate temperature range 1900° F. to 2100° F.

8. The method of making a sheathed electric heating unit comprising: producing an assembly of an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end of said sheath, a mass of compressible heat-conducting and electrical-insulating material in granular form arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, and a self-supporting hollow bushing of ceramic material surrounding the intermediate portion of said terminal and secured in place in said one end of said sheath to prevent the loss of said granular material therefrom, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and a metal carbonate, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in

the range 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof; cold working said assembly substantially to reduce the cross-sectional area of said sheath in order firmly to compact said granular material into a dense mass in engagement with said sheath and said resistance conductor and the inner end of said terminal and simultaneously to crush said bushing between said one end of said sheath and the adjacent intermediate portion of said terminal and to reduce the same in situ into finely divided form; and then subjecting said assembly to heat treatment including heating thereof to an elevated temperature in said range so that said finely divided ceramic material is sintered in situ into a unitary vitreous mass and subsequent cooling thereof so that said vitreous mass is congealed in situ into a self-supporting cellular and porous ceramic plug bonded both to the adjacent inner surface of said one end of said sheath and to the adjacent outer surface of the intermediate portion of said terminal.

9. The method of making a sheathed electric heating unit comprising: producing an assembly of an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and being electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end of said sheath, a mass of compressible heat-conducting and electrical-insulating material in granular form arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, and a self-supporting hollow bushing of ceramic material surrounding the intermediate portion of said terminal and secured in place in said one end of said sheath to prevent the loss of said granular material therefrom, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and calcium carbonate and borox, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in the range 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof; cold working said assembly substantially to reduce the cross-sectional area of said sheath in order firmly to compact said granular material into a dense mass in engagement with said sheath and said resistance conductor and the inner end of said terminal and simultaneously to crush said bushing between said one end of said sheath and the adjacent intermediate portion of said terminal and to reduce the same in situ into finely divided form; and then subjecting said assembly to heat treatment including heating thereof to an elevated temperature in said range so that said finely divided ceramic material is sintered in situ into a unitary vitreous mass and subsequent cooling thereof so that said vitreous mass is congealed in situ into a self-supporting cellular and porous ceramic plug bonded both to the adjacent inner surface of said one end of said sheath and to the adjacent outer surface of the intermediate portion of said terminal.

10. The method of making a sheathed electric heating unit comprising: producing an assembly of an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and being electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end

of said sheath, a mass of compressible heat-conducting and electrical-insulating material in granular form arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, a self-supporting hollow bushing of ceramic material surrounding the intermediate portion of said terminal and secured in place in said one end of said sheath to prevent the loss of said granular material therefrom, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and a metal carbonate, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in the range 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof, and a combustible washer frictionally secured to the intermediate portion of said terminal and engaging the extremity of said one end of said sheath to serve as a stopper to prevent the loss therefrom of said ceramic material in finely divided form; cold working said assembly substantially to reduce the cross-sectional area of said sheath in order firmly to compact said granular material into a dense mass in engagement with said sheath and said resistance conductor and the inner end of said terminal and simultaneously to crush said bushing between said one end of said sheath and the intermediate portion of said terminal and to reduce the same in situ into finely divided form and retained in place in said one end of said sheath by said washer; and then subjecting said assembly to heat treatment including heating thereof to an elevated temperature in said range and subsequent cooling thereof, whereby upon heating of said assembly said finely divided ceramic material is sintered in situ into a unitary vitreous mass and said washer is destroyed by combustion, and whereby upon cooling of said assembly said vitreous mass is congealed in situ into a self-supporting cellular and porous ceramic plug bonded both to the adjacent inner surface of said one end of said sheath and to the adjacent outer surface of the intermediate portion of said terminal.

11. The method of making a sheathed electric heating unit comprising: producing an assembly of an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and being electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end of said sheath, a mass of compressible heat-conducting and electrical-insulating material in granular form arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, a self-supporting hollow bushing of ceramic material surrounding the intermediate portion of said terminal and secured in place in said one end of said sheath to prevent the loss of said granular material therefrom, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and a metal carbonate, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in the range 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof, and a combustible washer formed essentially of synthetic organic resin and frictionally secured to the intermediate portion of said terminal and engaging the extremity of said one end of said sheath to serve as a stopper to prevent the loss therefrom of said ceramic material in finely divided form; cold working

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said assembly substantially to reduce the cross-sectional area of said sheath in order firmly to compact said granular material into a dense mass in engagement with said sheath and said resistance conductor and the inner end of said terminal and simultaneously to crush said bushing between said one end of said sheath and the intermediate portion of said terminal and to reduce the same in situ into finely divided form and retained in place in said one end of said sheath by said washer; and then subjecting said assembly to heat treatment including heating thereof to an elevated temperature in said range and subsequent cooling thereof, whereby upon heating of said assembly said finely divided ceramic material is sintered in situ into a unitary vitreous mass and said washer is destroyed by combustion, and whereby upon cooling of said assembly said vitreous mass is congealed in situ into a self-supporting cellular and porous ceramic plug bonded both to the adjacent inner surface of said one end of said sheath and to the adjacent outer surface of the intermediate portion of said terminal.

12. In the manufacture of a sheathed electric heating unit including a tubular metal sheath and a metal terminal projecting from the exterior into the end of the sheath and separated therefrom by an annular space, the method of sealing the end of said sheath to said terminal comprising: providing a compacted mass of finely divided ceramic material in the end of said sheath and filling said annular space, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and calcium carbonate and borax, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in the range of 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof, heating the assembly of said elements named to a temperature in said range in order to effect sintering in situ of said finely divided ceramic material into a unitary vitreous mass, and then cooling said assembly in order to effect congealing in situ of said vitreous mass into a self-supporting cellular and porous ceramic plug intimately bonded both to the adjacent inner surface of the end of said sheath and to the adjacent outer surface of said terminal.

13. In the manufacture of a sheathed electric heating unit including a tubular metal sheath and a metal terminal projecting from the exterior into the end of the sheath and separated therefrom by an annular space, the method of sealing the end of said sheath to said terminal comprising: providing a compacted mass of finely divided ceramic material in the end of said sheath and filling said annular space, wherein said ceramic material includes the following ingredients in the approximate amounts:

	Percent
Kaolin	28
Silica	27
Zirconium silicate.....	36
Calcium carbonate.....	3
Borax	5
Sodium silicate.....	1
	100

heating the assembly of said elements named to an elevated temperature in order to effect sintering of said finely divided ceramic material into a unitary vitreous mass, and then cooling said assembly in order to effect congealing of said vitreous mass into a self-supporting

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cellular and porous ceramic plug bonded both to the adjacent inner surface of the end of said sheath and to the adjacent outer surface of said terminal.

14. The method of making a sheathed electric heating unit comprising: producing an assembly of an elongated tubular metal sheath, an elongated electrical resistance conductor arranged within said sheath and spaced therefrom, an elongated metal terminal disposed at one end of said sheath, the inner end of said terminal being disposed interiorly of said one end of said sheath and spaced therefrom and being electrically connected to the adjacent end of said resistance conductor and the outer end of said terminal being disposed exteriorly of said one end of said sheath, a mass of compressible heat-conducting and electrical-insulating material in granular form arranged within said sheath and embedding both said resistance conductor and the inner end of said terminal and retaining the same in place in spaced relation with said sheath, and a self-supporting hollow bushing of ceramic material surrounding the intermediate portion of said terminal and secured in place in said one end of said sheath to prevent the loss of said granular material therefrom, wherein said ceramic material essentially comprises kaolin and silica and zirconium silicate and a metal carbonate, and wherein said ceramic material in finely divided form is characterized by sintering into a unitary vitreous mass upon heating thereof to an elevated temperature in the range 1900° F. to 2100° F. and said vitreous mass is characterized by congealing into a self-supporting cellular and porous ceramic body upon subsequent cooling thereof; cold working said assembly substantially to reduce the cross-sectional area of said sheath in order firmly to compact said granular material into a dense mass in engagement with said sheath and said resistance conductor and the inner end of said terminal and simultaneously to crush said bushing between said one end of said sheath and the adjacent intermediate portion of said terminal and to reduce the same in situ into finely divided form; heating said assembly in a reducing atmosphere for a given time interval at an elevated temperature in said range so that said finely divided ceramic material is sintered in situ into a unitary vitreous mass; and then cooling said assembly so that said vitreous mass is congealed in situ into a self-supporting cellular and porous ceramic plug bonded both to the adjacent inner surface of said one end of said sheath and to the adjacent outer surface of the intermediate portion of said terminal, and wherein the combination of said heating step and said cooling step also effects the relief of stresses in said sheath that were introduced therein by said preceding cold working step.

15. The method set forth in claim 14, wherein said reducing atmosphere is composed predominantly of nitrogen, hydrogen and carbon monoxide.

16. The method set forth in claim 14, wherein said reducing atmosphere has the approximate composition:

	Percent
N	65
H	18
CO	11
CO ₂	5
CH ₄	1
	100

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