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Thomas et al.

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[54] **METHOD FOR MAKING THERMOSTAT METAL**

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[52] **U.S. Cl.** **29/487**, 29/497, 29/497.5, 29/498

[51] **Int. Cl.** **B23k 31/02**

[58] **Field of Search** 29/195.5, 487, 497.5, 498, 29/497

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[57] **ABSTRACT**

A process for making thermostat metals embodying a plurality of oxidizable metal layers such as layers of iron or iron alloy, is shown to comprise the steps of cleaning the surfaces of thin strips of such metals having relatively high and low coefficients of thermal expansion respectively, interfacially contacting the cleaned surfaces of the strips, squeezing the strips together with sufficient reduction of the strip materials to form incipient metallurgical bonds between the strips in the solid phase, and heating the resulting bonded composite material to a sufficiently high temperature for substantially completely dispersing oxides from the interfacially contacted surfaces of the strips into the strip material and for increasing the bonds between the strips by diffusion in the strip materials for substantially completely bonding the interfacially contacted surfaces of the strips together in the solid phase.

10 Claims, 4 Drawing Figures

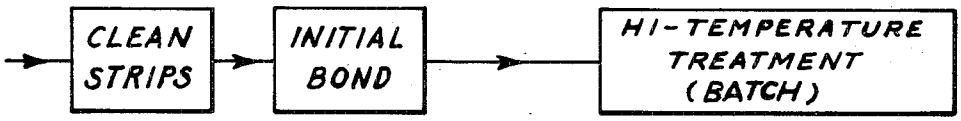


Fig. 1.

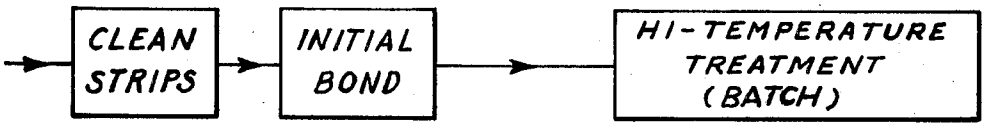


Fig. 2.

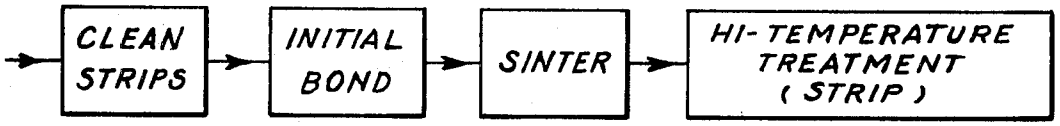


Fig. 3.

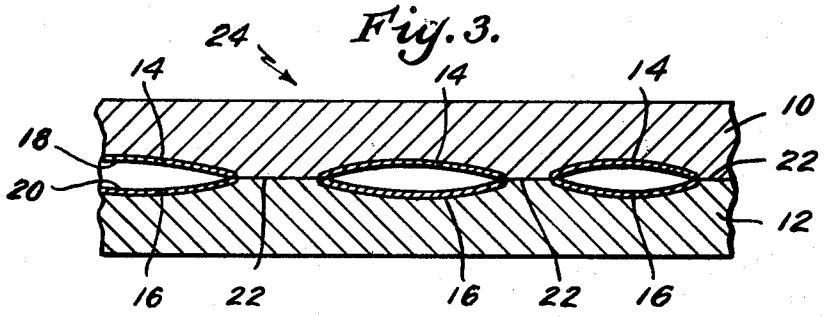
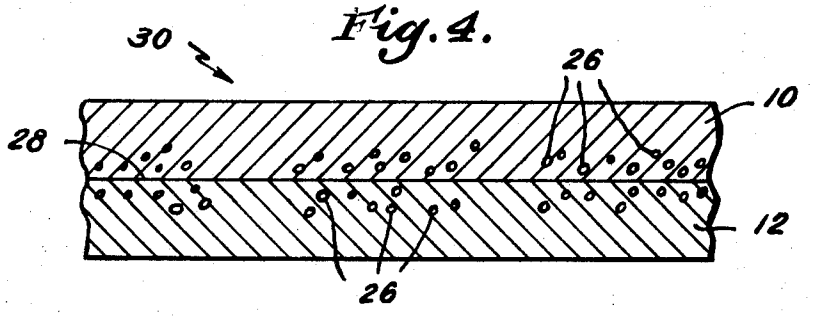


Fig. 4.



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METHOD FOR MAKING THERMOSTAT METAL

Thermostat metal embodying two or more metallurgically bonded layers of metals of different coefficients of thermal expansion are customarily used in very thin form so that, when exposed to temperature changes, the thermostat metals can bend or deform in response to the different thermal expansions of the metal layers. As will be understood, this use of thermostat metals subjects the bond between the metal layers to considerable stress so that relatively high-quality metallurgical bonds are required. When thermostat metals embodying certain materials such as one or more layers of iron or iron alloy materials have been made prior to the present invention, it has been conventional practice to begin the process of manufacture with relatively thick ingots of metal in order to achieve the desired quality of bond between the ingot materials. These ingots were heated to a temperature on the order of 2,000° F. and, while in heated condition, were squeezed together in a rolling mill with about 60 to 80 percent reduction in the thickness of the ingots. The bonded ingots were then subjected to a series of alternate rerolling and annealing steps to reduce the thickness of the bonded material to the relatively small thickness usually required in thermostat metals. This prior art process was successful in forming thermostat metals having metallurgical bonds of the desired quality but the requirement for roll squeezing the ingots while hot and for applying great pressure to bring about the required substantial reduction in the thickness of the thick ingot material, and particularly the subsequent series of rerolling and annealing steps required for reducing the bonded composite material to useful thicknesses, made the process expensive to perform and added considerably to the cost of thermostat metals formed of iron or iron alloy materials and the like.

It is an object of this invention to provide novel and improved processes for manufacture of thermostat metals, particularly those embodying one or more layers of iron or iron alloy materials; to provide such processes which produce such thermostat metals at a substantially lower cost than has previously been possible; to provide such improved processes by which such thermostat metals can be economically manufactured with high-quality metallurgical bonds; and to provide such processes by which such thermostat metals can be economically manufactured with carefully controlled and uniform thermostatic properties.

Briefly described, the novel and improved process of this invention for manufacturing thermostat metals, particularly those embodying one or more layers of certain materials such as iron and iron alloy materials, comprises the steps of cleaning the surfaces of thin, elongated strips of such metal materials which have relatively high and low coefficients of thermal expansion respectively. The clean surfaces of these metal strips are then interfacially contacted and the strips are squeezed together with sufficient reduction in thickness of the strip materials to form incipient or partial metallurgical bonds between the strip materials in the solid phase. Preferably this squeezing is performed without heating the strip materials by passing the strips in superimposed relation between the rolls of a rolling mill for reducing the thickness of the strip materials by about 50 percent or more of their initial thickness. In accordance with this invention, this resulting, initially bonded composite material is then heated to a sufficiently high temperature, preferably in the range from about 0.5 to 0.7 of the absolute melting temperature expressed in degrees Kelvin of the strip material having the highest melting temperature, for substantially dissolving or dispersing all oxides from the interfacially contacting surfaces of the strips into the strip materials and for increasing the bonds between the strips by diffusion between the strip materials until the interfacially contact surfaces of the strips are substantially completely bonded together in the solid phase. In a preferred embodiment of this invention, the initially bonded composite material is heated to the desired high temperature in a single batch and is maintained at that temperature until dispersal of the oxides from the strip surfaces has been completed and until the bonds between the strips have increased to the point where the strip

surfaces are substantially completely bonded together. In an alternate embodiment of this invention, the initially bonded composite material is preliminarily heated or sintered at a temperature below the high temperature above-described for partially increasing the bonds between the strip materials so that the bond strength is sufficient to permit easy handling of the composite material. The composite material is subsequently heated to a higher temperature progressively along the length of the composite material for dispersing oxides from the interfacially contacting surfaces of the strips or layers into the composite material and for completing the bonds between the strips. For example, the initially bonded and sintered composite material is subsequently passed through a conventional strip annealing apparatus where the composite material is heated to the desired higher temperature progressively along the length of the material, the higher temperature and speed with which the composite material is moved through the strip annealer being selected to accomplish the dispersal of oxides and completion of the strip bonds in the manner above-described.

Other objects, advantages and details of the novel and improved process of this invention appear in the following detailed description of preferred embodiments of the invention, the detailed description referring to the drawings in which:

FIGS. 1 and 2 are block diagrams illustrating preferred embodiments of the method of this invention;

FIG. 3 is a partial longitudinal section view through the initially bonded composite material formed as an intermediate product in the process of this invention; and

FIG. 4 is a section view similar to FIG. 3 illustrating properties of the thermostat metal formed by the process of this invention.

In accordance with the method of this invention, as illustrated in FIG. 1, thin, elongated strips of certain materials, such as iron or iron alloy materials, of relatively high and low coefficients of thermal expansion respectively are cleaned for removing gross contaminants from the surfaces of the strips. In this regard, note that the term "iron alloys" as used herein is intended to include metal alloys of which iron constitutes at least 50 percent of the alloy. This cleaning is performed in any conventional manner and may include the steps of passing the strip materials through degreasing baths, heating the strips in a reducing atmosphere for removing heavy oxide films from the strip surfaces, and abrading, grinding or wire brushing of the strip surfaces for removing barriers to bonding from the surfaces. For example, where a thermostat metal embodying layers of Alloy B and Alloy 10 metals is to be formed in accordance with this invention, elongated strips of these metals having thicknesses from about 0.040 to 0.200 inches and widths from 2 to 14 inches or more are preferably fed from coils through any conventional degreasing bath and are then subjected to wire brushing in air on the principal surfaces of the strips for removing gross contaminants from the strip surfaces. Alloy B comprises an iron alloy of relatively high coefficient of thermal expansion embodying about 22 percent nickel, 3 percent chromium and the balance iron; whereas Alloy 10 comprises an iron alloy of relatively low coefficient of thermal expansion embodying about 36 percent nickel and the balance iron.

The thin iron or iron alloy strip materials are then brought together so that principal cleaned surfaces of the strips are interfacially contacted, and the strips are squeezed together with sufficient reduction in the thickness of the strip materials to form incipient or partial metallurgical bonds between the strips in the solid phase. For example, the cleaned strip materials are preferably fed from coils into superimposed relation to each other and are passed in this superimposed relation between the rolls of a rolling mill where the strips are squeezed together with sufficient reduction to form the desired solid-phase bonds. Most economically, the strips are squeezed together at room temperature or at a temperature slightly above room temperature as established by whatever

heating of the strip materials results from the cleaning steps as described above. However, the iron or iron alloy strips may also be heated to higher temperatures up to about 1,000° F. prior to squeezing to facilitate reduction of the strips within the scope of this invention.

In this regard, it should be noted that the iron or iron alloy materials conventionally used in forming thermostat metals tend to be coated with surface oxides even though efforts are made to remove such oxide films. As a result, when the strips are squeezed together, these oxides tend to retard formation of metallurgical bonds between the strips. However, where sufficient reduction of the strip materials is achieved, the oxide films are broken apart so that portions of the virgin metal of the strip materials are brought into contact and are bonded together during the described squeezing step to form the desired incipient metallurgical bonds. That is, as is illustrated in FIG. 3, the strips **10** and **12** of relatively high and low coefficients of thermal expansion respectively tend to have oxide films **14** and **16** on the interfacially contacting surfaces **18** and **20** of the strips, but, when the strips are squeezed together with sufficient reduction in the thickness thereof, the oxide films are broken apart and incipient or partial metallurgical bonds are formed between the strip materials as indicated at **22**. This leaves the generally lens-shaped inclusions between the strips as illustrated in FIG. 3 in which the strip surfaces remaining covered by the films **14** and **16** are not bonded together. It should be understood that although the films **14** and **16** are shown spaced in FIG. 3 for clarity of illustration, the films **14** and **16** will normally be in contacting relation to each other within these inclusions. For accomplishing this bonding, the iron or iron alloy strip materials are preferably squeezed together with about 50 to 80 percent reduction in the total thickness of the strip materials.

In accordance with this invention, the initially bonded composite material **24** illustrated in FIG. 3 is then subjected to a high-temperature treatment, the temperature at which the composite is treated being selected to accomplish the dual purpose of dissolving or dispersing the oxides of the films **14**, **16** from the interfacially contacting surfaces **18**, **20** of the strips **10**, **12** into the strip materials and of increasing the incipient bonds between the strips by diffusion within the strip materials until the interfacially contacting surfaces of the strips are completely bonded together in the solid phase. In this regard, it is noted that diffusion can be induced in the iron and iron alloy materials conventionally used in thermostat metals at temperatures on the order of 1,500° F. or less and that treatment of the composite material **24** at this temperature increases the incipient bonds formed in the initially bonded composite **24** to at least some extent. However, dispersal of the oxide films from the interfacially contacting surfaces of the strips **10**, **12** must be accomplished before the strips can be completely bonded together and this dispersal of oxides occurs in such iron and iron alloy materials within a reasonable period of time only when the composite material is treated for a sufficient period of time at a temperature in the range from about 0.5 to 0.7 of the absolute melting temperature of the strip materials as expressed in degrees Kelvin

Therefore, in a method of this invention illustrated in FIG. **1**, a batch or quantity of initially bonded composite material **24** is subjected to high-temperature treatment in a conventional bell annealing furnace or the like. For example, where the composite material embodies Alloy B and Alloy 10 materials as above described, which materials have absolute melting temperatures of approximately 1,800° K. (about 2,780° F.) and 1,760° K. (about 2,710° F.) respectively, coils of the initially bonded composite material **24** embodying about 2,000 pounds of the material are brought to a temperature in the range from about 1,155° K. (about 1,620° F.) to about 1,533° K. (about 2,300° F.) in a bell annealing furnace for a period from about ½ to 2 hours, the time of treatment being selected with respect to the temperature of the treatment for substantially completely dissolving or dispersing the oxide on the interfacially contacting surfaces of the strips into the strip materials and for substantially completely bonding the strip surfaces together. Preferably for example, the initially bonded composite material embodying Alloy B and Alloy 10 metal layers is treated at a temperature of about 1,433° K. (about 2,100° F.) for a period of about 1 hour. During this treatment, the interfacial oxides **14**, **16** illustrated in FIG. **3** are substantially completely dissolved or dispersed away from the strip surfaces into the strip materials as indicated at **26** in FIG. **4** and only a few small oxide particles remain at the interface between the strips. These remaining oxide particles are substantially spheroidized so that they have minimum effect interfering with the bond strength at the interface. The composite material is also characterized by grain growth after this treatment, which grain growth is indicative of the diffusion which increases the incipient bond illustrated at **22** in FIG. **3** so that the interfacially contacting surfaces of the Alloy B and Alloy 10 strips or layers are substantially completely bonded together as indicated at **28** in FIG. **4**, thereby to form a substantially fully bonded composite thermostat material **30**.

The composite thermostat material **30** formed in accordance with the method of this invention is found to have excellent bond strength while the material has substantially the same thermostatic properties as comparable thermostat materials formed by prior art processes. The material as bonded and heat treated is also relatively thin so that the material is of a useful thickness for some thermostat metal applications without requiring additional reduction of the material thickness. However, if desired, the thin, fully bonded composite material may be subjected to some rerolling, and, if desired, to annealing after rerolling for reducing the thickness of the composite material to the desired final gage without reducing the quality of the bond between the composite metal layers. Such rerolling, or rerolling and annealing can also be performed for the purpose of controlling the grain size in the layers of the composite material if desired. As such rerolling and annealing can be performed in any conventional manner, the rerolling and annealing procedure is not further described herein.

It should be understood that thermostat metals embodying a variety of materials can be prepared in accordance with the method of this invention. For example, any of the iron or iron alloy materials in Table I set forth below can be combined with any of the other materials in Table I according to the method of this invention to form a thermostat material, provided, of course, that the materials selected from the table display a suitable difference in coefficient of thermal expansion to provide the resulting composite thermostat metal with the desired flexivity.

TABLE I

	Nickel	Chromium	Iron	Manganese	Aluminum	Molybdenum	Cobalt	Carbon
Alloy B	22.0	3.0	Bal.					0.5
Alloy C	19.4	2.25	Bal.					
Alloy D	14.65		Bal.	9.5	5.1			
Alloy E	25.0	8.5	Bal.					
Alloy G	18.0	11.5	Bal.					
Alloy GA	18.0	10.0	Bal.				3.0	
Alloy GB	19.0	7.0	Bal.					
Alloy H	14.0		Bal.	5.0				0.5
Alloy K			Bal.					
Alloy L	25.0		Bal.	4.0				

TABLE I—Continued

	Nickel	Chromium	Iron	Manganese	Aluminum	Molybdenum	Cobalt	Carbon
Alloy M	8.0	18.0	Bal.					
Alloy 15	32.0		Bal.			1.0	1.0	
Alloy 71		16.5	Bal.		4.5			
Alloy 10	36.0		Bal.					
Alloy 11	38.65		Bal.					
Alloy 12	31.0	8.0	Bal.				8.0	
Alloy 13	32.0		Bal.			1.0	15.0	
Alloy 14	38.0	7.0	Bal.					
Alloy 15	32.0		Bal.			1.0	1.0	
Alloy 20	40.0		Bal.					
Alloy 30	42.0		Bal.					
Alloy 40	45.0		Bal.					
Alloy 50	50.0		Bal.					
Alloy 70		17.0	Bal.					

In accordance with conventional procedure, the alloys set forth in this table may also include small quantities of additional constituents present as impurities in the alloys.

When forming thermostat metals of two or more iron or iron alloy materials, the temperature at which the initially bonded composite material is treated in the manner set forth above is preferably selected so that the treatment temperature is greater than 0.5 times the absolute melting temperature of whichever iron or iron alloy material has the higher melting temperature so that oxide films and the interfacially contacting surface of the layers can be dispersed into both materials.

It should also be understood that one or more of the alloys set forth in Table I can be combined with other alloy compositions having high melting temperatures above the final treatment temperature required by the method of this invention. For example, alloys selected from Table I may be combined with alloys selected from Table II set forth below for forming thermostat metals within the scope of this invention.

TABLE II

alloy	nickel	manganese	iron	copper	cobalt	chromium
LA	20.0	6.0	Bal.	--		--
P	10.0	72.0	--	18.0	--	--
PA	15.0	75.0	--	10.0	--	--
80	--	--	Bal.	--	57.0	9.0

In accordance with conventional procedure, the alloys set forth in this table may also include small quantities of additional constituents present as impurities in the alloys. When an alloy from Table I is combined with an alloy from Table II, the high temperature treatment to which the initially bonded composite material thus formed is subjected is preferably controlled so that the temperature of treatment is equal to at least 0.5 of the absolute melting temperature of the iron or iron alloy material embodied in the composite.

Although the high-temperature treatment step of the method of this invention has been described above in terms of a batch process, it should be understood that an initially bonded composite material formed in the manner previously described can also be subjected to high-temperature treatment by moving the initially bonded composite material through a conventional strip-annealing apparatus, the temperature of treatment being selected with respect to the speed at which the initially bonded composite is moved through the strip annealer to accomplish the dual purpose of dissolving or dispersing oxides from the interfacially contacting surfaces of the initially bonded composite and of inducing diffusion in the strip materials to substantially completely bond the layers of the composite material together in the manner previously described. For facilitating handling of an initially bonded composite material in moving this composite material through a strip annealer, the initially bonded composite is preferably subjected to a preliminary batch treatment in a conventional bell annealing furnace or the like for inducing at least a limited amount of diffusion or sintering within the strip materials to increase the strength of the initial bond formed between the layers of the initially bonded composite material. That is, as is illustrated in FIG. 2, after cleaning and initial bonding of the strip materials to form an initially bonded composite, the composite is placed in a conventional bell annealing furnace and is heated to a temperature on the order of 1,500° F. for a period of 15 minutes to 1 hour to increase the bond strength in the composite by inducing at least a limited amount of diffusion in the strip materials. This composite material with its partially strengthened bond is then passed through a strip annealer or the like wherein the material is subjected to the desired high temperature treatment for dispersing oxide films from the interfacially contacted surfaces of the layers within the composite and for inducing additional diffusion in the strip materials until the strip materials are substantially completely bonded together.

For example, where a thermostat metal is to be formed of Alloy B and Alloy 10 as above described in accordance with the method of FIG. 2, the principle surfaces of the strips of material of these alloys are wire brushed in air for removing gross contaminants from the principal strip surfaces. With the cleaned surfaces of the strips in contact with each other, the strips are then passed through a rolling mill where the strips are squeezed together with approximately 70 percent reduction in the thicknesses thereof for forming an initially bonded composite material. This composite material is then subjected to sintering in a bell annealing furnace at a temperature of about 1,500° F. for a period of about 1 hour. This intermediate treatment increases the bond strength of the composite material. After the initially bonded and sintered material is removed from the bell annealing furnace, the partially strengthened composite material is subsequently passed through a conventional strip annealer with a residence time of from 5 to 60 minutes at a temperature of approximately 2,000° F. for substantially completely dispersing oxide films from the interfacially contacting surfaces of the strips and for substantially completing the bond between the layers of the composite material, thereby to form a thermostat metal material.

It should be understood that although particular embodiments of the method of this invention have been described by way of illustration, this invention includes all modifications and equivalents thereof which fall within the scope of the appended claims.

We claim:

1. A method for forming a composite thermostat metal comprising the steps of interfacially contacting clean surfaces of at least two layers of metal having relatively high and relatively low coefficients of thermal expansion respectively, at least one of said layers of metal being selected from the group consisting of iron and iron alloys having an oxide surface film on the clean surface thereof, roll squeezing said layers of metal together at a temperature in the range from room temperature to about 1,000° F. with reduction in the thickness thereof for breaking said oxide film apart and for forming a partial metallurgical bond between said metal layers in the solid phase, and heating said metal layers to a temperature below the melting temperatures thereof for substantially completely dispersing oxides from said interfacially contacted surface of the said iron or iron alloy layer into said iron or iron

alloy layer and for inducing diffusion in said metal layers to substantially completely bond said interfacially contacting surfaces of said layers together in the solid phase.

2. A method as set forth in claim 1 wherein said metal layers are heated to a temperature equaling from 0.5 to 0.7 of the absolute melting temperature of said selected iron or iron alloy layer.

3. A method as set forth in claim 2 wherein said partially bonded metal layers are initially heated to a relatively lower temperature for inducing a limited amount of diffusion in said metal layers to increase the strength of the bond between said metal layers.

4. A method for forming a composite metal comprising the steps of continuously advancing at least two elongated, thin strips of metal having clean surfaces thereon into interfacial contact, said strips embodying metals of relatively high and relatively low coefficients of thermal expansion respectively and at least one of said strips embodying a metal selected from the group consisting of iron and iron alloys having an oxide surface film on the contacted surface thereof, continuously roll squeezing said metal strips together as they are interfacially contacted at a temperature in the range from room temperature to about 1,000° F. with reduction in the thickness thereof for breaking said oxide film apart and for forming a partial metallurgical bond between said metal strips in the solid phase, and heating said metal strips to a temperature below the melting temperatures thereof for substantially completely dispersing oxides from said interfacially contacted surface of said iron or iron alloy strip into said metal strip and for inducing diffusion in the metal strips to substantially completely bond said interfacially contacted surfaces of said metal strips together in the solid phase.

5. A method as set forth in claim 4 wherein said metal strips are heated to a temperature equaling from 0.5 to 0.7 of the absolute melting temperature of said selected iron or iron alloy for dispersing oxides from said interfacially contacted surface of said metal strip embodying said iron or iron alloy into said metal strip and for inducing diffusion in said metal strips to substantially completely bond said interfacially contacting surfaces of said metal strips together in the solid phase.

6. A method as set forth in claim 5 wherein said partially bonded metal strips are initially heated to a relatively lower temperature for inducing a limited amount of diffusion in the metal strips to increase the strength of the partial bond between said metal strips.

7. A method as set forth in claim 5 wherein at least one of said iron or iron alloy strips comprises a material selected from the group of materials having nominal compositions by weight, consisting of an alloy of 0.5% carbon, 22.0% nickel, 3.0% chromium and the balance iron; an alloy of 19.4% nickel, 2.25% chromium and the balance iron; an alloy of 5.1% aluminum, 9.5% manganese, 14.65% nickel and the balance iron; an alloy of 8.5% chromium, 25.0% nickel and the balance iron; an alloy of 11.5% chromium, 18% nickel and the balance iron; an alloy of 3.0% molybdenum, 10.0% chromium, 18.0% nickel and the balance iron; an alloy of 7.0% chromium, 19.0% nickel and the balance iron; an alloy of 0.5% carbon, 5.0% manganese, 14.0% nickel and the balance iron; an alloy of 4.0% manganese, 25.0% nickel and the balance iron; an alloy of 8.0% nickel, 18.0% chromium and the balance iron; an alloy of 1.0% cobalt, 1.0% molybdenum, 32.0% nickel and the balance iron; an alloy of 4.5% aluminum, 16.5% chromium, and the balance iron; an alloy of 36.0% nickel and the balance iron; an alloy of 38.5% nickel and the balance iron; an alloy of 8.0% cobalt, 8.0% chromium, 31.0% nickel and the balance iron; an alloy of 1.0% molybdenum, 15.0% cobalt, 32.0% nickel and the balance iron; an alloy of 7.0% chromium, 38.0% nickel and the balance iron; an alloy of 40.0% nickel and the balance iron; an alloy of 42.0% nickel and the balance iron; an alloy of 45.0% nickel and the balance iron; an alloy of 50.0% nickel and the balance iron; and an alloy of 17.0% chromium and the balance iron.

8. A method as set forth in claim 5 wherein each of said metal strips comprises a material selected from the group of materials having nominal compositions by weight, consisting of an alloy of 0.5% carbon, 22.0% nickel, 3.0% chromium and the balance iron; an alloy of 19.4% nickel, 2.25% chromium and the balance iron; an alloy of 5.1% aluminum, 9.5% manganese, 14.65% nickel and the balance iron; an alloy of 8.5% chromium, 25.0% nickel and the balance iron; an alloy of 11.5% chromium, 18% nickel and the balance iron; an alloy of 3.0% molybdenum, 10.0% chromium, 18.0% nickel and the balance iron; an alloy of 7.0% chromium, 19.0% nickel and the balance iron; an alloy of 0.5% carbon, 5.0% manganese, 14.0% nickel and the balance iron; an alloy of 4.0% manganese, 25.0% nickel and the balance iron; an alloy of 8.0% nickel, 18.0% chromium and the balance iron; an alloy of 1.0% cobalt, 1.0% molybdenum, 32.0% nickel and the balance iron; an alloy of 4.5% aluminum, 16.5% chromium, and the balance iron; an alloy of 36.0% nickel and the balance iron; an alloy of 38.5% nickel and the balance iron; an alloy of 8.0% cobalt, 8.0% chromium, 31.0% nickel and the balance iron; an alloy of 1.0% molybdenum, 15.0% cobalt, 32.0% nickel and the balance iron; an alloy of 7.0% chromium, 38.0% nickel and the balance iron; an alloy of 40.0% nickel and the balance iron; an alloy of 42.0% nickel and the balance iron; an alloy of 45.0% nickel and the balance iron; an alloy of 50.0% nickel and the balance iron; and an alloy of 17.0% chromium and the balance iron.

9. A method as set forth in claim 7 wherein at least one of said metal strips comprises a material selected from the group of materials, having nominal compositions by weight, consisting of an alloy of 6.0% manganese, 20.0% nickel and the balance iron; an alloy of 10.0% nickel, 18.0% copper and the balance manganese; an alloy of 10.0% copper, 15.0% nickel and the balance manganese; and an alloy of 9.0% chromium, 57.0% cobalt and the balance iron.

10. A method for forming a composite thermostat metal comprising the steps of cleaning the principal surfaces of at least two elongated, thin metal strips for removing gross contaminants therefrom, said strips embodying metal materials of relatively high and relatively low coefficients of thermal expansion respectively and at least one of said metal strips comprising a material selected from the group of materials having nominal compositions by weight, consisting of an alloy of 0.5% carbon, 22.0% nickel, 3.0% chromium and the balance iron; an alloy of 19.4% nickel, 2.25% chromium and the balance iron; an alloy of 5.1% aluminum, 9.5% manganese, 14.65% nickel and the balance iron; an alloy of 8.5% chromium, 25.0% nickel and the balance iron; an alloy of 11.5% chromium, 18% nickel and the balance iron; an alloy of 3.0% molybdenum, 10.0% chromium, 18.0% nickel and the balance iron; an alloy of 7.0% chromium, 19.0% nickel and the balance iron; an alloy of 0.5% carbon, 5.0% manganese, 14.0% nickel and the balance iron; an alloy of 4.0% manganese, 25.0% nickel and the balance iron; an alloy of 8.0% nickel, 18.0% chromium and the balance iron; an alloy of 1.0% cobalt, 1.0% molybdenum, 32.0% nickel and the balance iron; an alloy of 4.5% aluminum, 16.5% chromium, and the balance iron; an alloy of 36.0% nickel and the balance iron; an alloy of 38.5% nickel and the balance iron; an alloy of 8.0% cobalt, 8.0% chromium, 31.0% nickel and the balance iron; an alloy of 1.0% molybdenum, 15.0% cobalt, 32.0% nickel and the balance iron; an alloy of 7.0% chromium, 38.0% nickel and the balance iron; an alloy of 40.0% nickel and the balance iron; an alloy of 42.0% nickel and the balance iron; an alloy of 45.0% nickel and the balance iron; an alloy of 50.0% nickel and the balance iron; and an alloy of 17.0% chromium and the balance iron, said iron or iron alloy strip having an oxide surface film on said cleaned surfaces thereof, continuously advancing said cleaned metal strips into contact with each other for interfacially contacting cleaned surfaces of said strips continuously roll squeezing said metal strips together as they are interfacially contacted at a temperature in the range from room temperature to about 1,000° F. with reduction in the thickness of each of said metal strips for

breaking said oxide film apart and for forming a partial metallurgical bond between said metal strips in the solid phase, and heating said metal strips to a temperature in the range from 0.5 to 0.7 of the absolute melting temperature of said iron or iron alloy strip for dispersing oxides from said interfacially contacted surface of said iron or iron alloy strip into said metal strip and for inducing diffusion in the metal strips to substantially completely bond said interfacially contacting surfaces of said metal strips together in the solid phase, said temperature being below the melting temperature of all of said metal strips.

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