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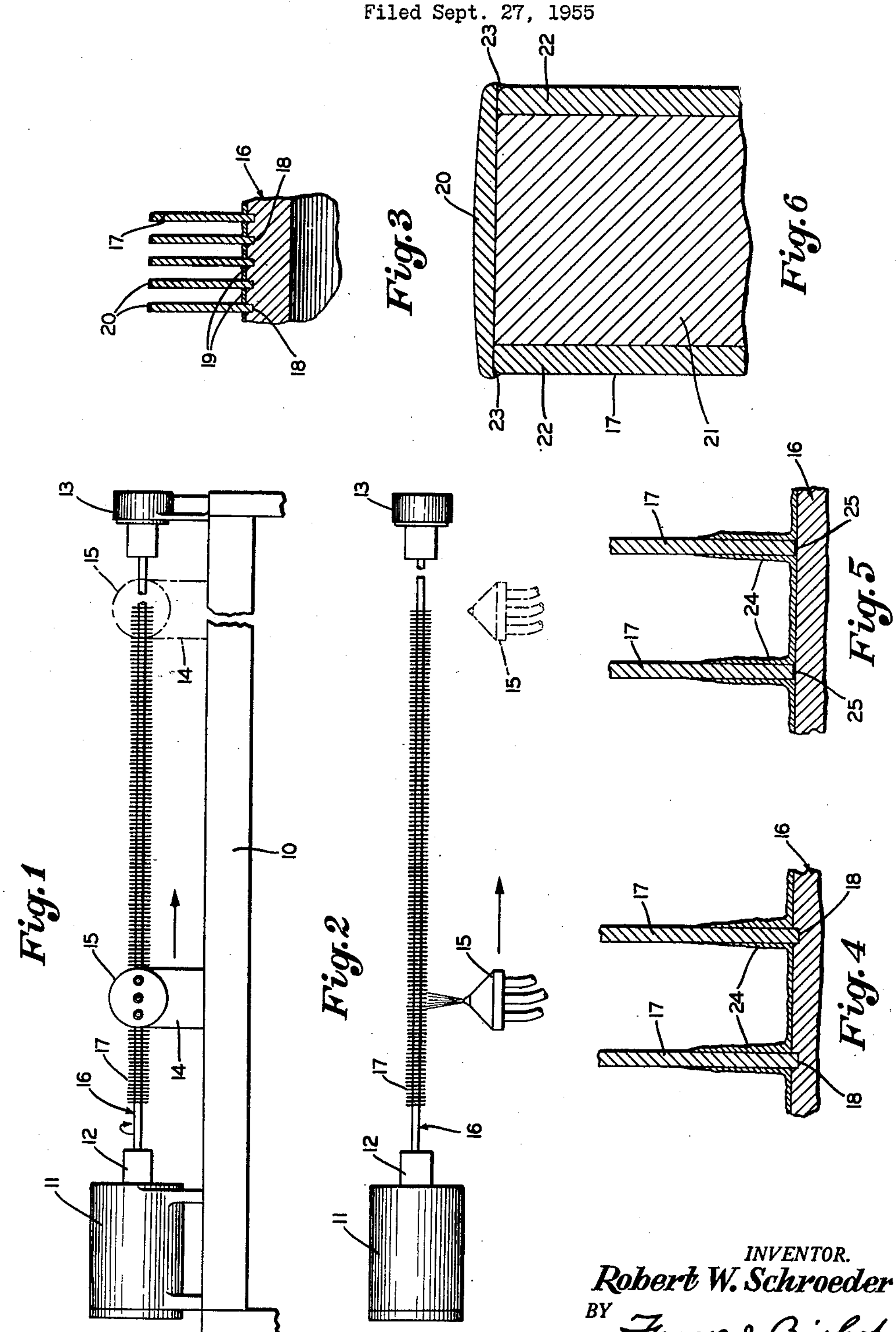

INVENTOR.
Robert W. Schroeder
BY Frease & Bishop
ATTORNEYS

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MANUFACTURE OF BRAZED FINNED TUBING AND THE LIKE

Robert W. Schroeder, Massillon, Ohio, assignor to The Griscom-Russell Company, Massillon, Ohio, a corporation of Delaware

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The invention relates to the manufacture of finned tubing suitable for use in heat exchangers and other purposes, and more particularly to a method for expeditiously and economically manufacturing brazed finned tubing whereby the fins are bonded to the tubing along the entire interface.

In use, such finned tubing is subjected to extremely high temperatures and high pressures and is frequently exposed to highly corrosive fluids. The tube must therefore necessarily be formed of a high temperature resistant, high strength and corrosion-resisting material such as stainless steel. For the purposes of obtaining the maximum heat exchange, the fins should be formed of a high heat conducting material such as copper.

It is important that the exterior surfaces of such a copper fin be protected against the corrosive action of fluids to which they are exposed. For this purpose stainless steel may be clad upon the copper fin. The outer edge of the fin may be protected by using a copper fin clad on only one side with stainless steel and folding the fin material upon itself and attaching the edges of the folded fin to the tube.

However, in many instances the finned tube may comprise an unfolded fin of single thickness, in which the copper fin is clad on both sides with stainless steel. Thus, the outer edge of the copper is exposed. The invention contemplates the protection of this outer edge of the fin by building up a deposit of brazing alloy thereon to entirely seal and protect the copper.

Two types of fins are commonly used in the construction of such finned tubing. One type of fin comprises straight, flat ribbons extending longitudinally of the tube and attached thereto in radially disposed position. The other type of fin comprises a ribbon spirally wound around the tube, with the inner edge thereof seated in a spiral groove in the tube or contacting the periphery thereof. The spirally wound fin may be very thin, say .008" to .010" thick, and there may be as many as twenty to thirty winds per inch of tube length.

While the present invention is applicable to either of these types of finned tubes, it is illustrated and described herein as applied to the spiral fin type to which it is especially adapted. These spiral fins are stressed and stretched as they are wound around the tube, which tends to hold the fin upon the tube.

If the fin stress is released, the bond between the fin and tube becomes less secure. A differential in expansion of the two materials may aggravate these conditions, causing the bond between the fin and tube to be destroyed.

In the manufacture of such finned tubing for use in heat exchangers it is desirable that this bond be obtained and maintained during use at high temperature, as otherwise the conductivity is reduced, proportionately decreasing the effectiveness of the tubing as a heat exchange medium.

The invention contemplates the application of a deposit of brazing alloy upon the tube at and around the base of the fin so as, after subsequent brazing, to obtain and

maintain a tight secure bond between the tube and the fin under all conditions to which the finned tube may be subjected in normal use.

Likewise, where the fin is formed of a copper ribbon clad on both sides with stainless steel, with the inner edge thereof bonded to the tube, the outer edge of the copper fin may be sealed and protected against corrosive fluids by building up a deposit of brazing alloy thereon. In order to facilitate adherence of the brazing alloy, the fin tip may be roughened by shot or grit blasting or by means of a knurled roll. The exterior surface of the tube may, in some instances, require similar roughening in order to facilitate adherence of the brazing alloy to the tube and the base of the fin tip.

It is therefore a primary object of the invention to provide a method of expeditiously and economically manufacturing brazed finned tubing whereby a tight and secure bond is obtained and maintained between the fin and tubing along the entire interface.

Another object is to provide such a method by which the brazing alloy is caused to flow into all small crevices between the tube and the fin.

A further object is to provide a method of manufacturing brazed finned tubing which includes heating of the tube and the fin, spraying powdered brazing alloy onto desired portions of the heated parts so that it will adhere thereto as a sintered deposit, and then furnace brazing the finned tube to cause the brazing alloy to flow over desired areas and also into all fine crevices between the tube and fin.

A still further object is to provide for the manufacture of brazed finned tubing by placing a finned tube in a lathe and locating an oxy-acetylene torch in the tool post of the lathe so that the flame thereof will impinge upon the tube and the fin, rotating the finned tube and simultaneously moving the torch from one end of the fin to a point spaced therefrom to preheat the adjacent end portions of the tube and fin, then backing up the torch to the starting point, and then spraying powdered brazing alloy from the torch upon the tube and fin as the torch is continuously moved toward the other end of the fin.

Another important object of the invention is to provide a method of protecting the outer edge of the fin by depositing brazing alloy thereon at the same time that the brazing alloy is deposited on the tube at and around the base of the fin.

A further object is to provide for protecting the outer edge of the fin by first roughening said outer edge, then depositing brazing alloy upon the roughened outer edge of the fin, and then melting and flowing the deposited alloy.

A still further object is to provide such a method of manufacturing brazed finned tubing, which consists in applying a sintered deposit of powdered brazing alloy to a finned tube in the manner referred to, and then furnace brazing the finned tube to cause the brazing alloy to flow outward on the fin and into fine crevices between the tube and fin.

These and other objects which will be apparent to those skilled in the art, or which may be later pointed out, may be accomplished by the methods, constructions, arrangements, parts, combinations and sub-combinations comprising the present invention, the nature of which is set forth in the following general statement, a preferred embodiment of which—illustrative of the best mode in which applicant has contemplated applying the principles—is set forth in the following description and illustrated in the accompanying drawing, and which is particularly and distinctly pointed out and set forth in the appended claims forming part hereof.

The method and apparatus comprising the invention are applicable to the manufacture of brazed finned tubing provided either with fins wound spirally around the tubes or fins extending longitudinally of the tube. For the purpose of illustration, the invention is shown and described as applied to finned tubing of the spiral fin type, and the following general statement briefly describes the manner in which the invention may be carried out.

In general terms, the invention comprises a method of and apparatus for applying brazing alloy to a tube having a fin spirally wound around the outer surface thereof, so as to securely bond the base of the fin to the tube and also to seal and protect the outer edges of the fin. The invention is carried out by rotating the finned tube and heating one end portion thereof, and then spraying powdered brazing alloy upon the rotating tube to apply a sintered deposit of brazing alloy thereto at the base of the fin and upon the outer edge of the fin, by a torch moved from the preheated end of the tube to the other end thereof, the tube and fin being heated by the torch ahead of the application of the brazing alloy.

This may be accomplished upon a lathe, the finned tube being mounted for rotation between the head stock and tail stock of the lathe, and the torch being mounted upon the tool post. A torch is used from which a desired powdered metallic brazing alloy is blown by compressed air onto the work, with and through an oxyacetylene flame which heats the metallic powder and deposits the same on the work on which it adheres in sintered condition.

The method is performed by first using the torch without the metallic brazing powder, to preheat one end portion of the rotating finned tube to the desired temperature. The tool post, upon which the torch is mounted, is then backed up to the starting point and powdered brazing alloy is fed to the torch, which is then advanced along the length of the tube by the usual lead screw which operates the tool post of the lathe. A deposit of sintered brazing alloy is thus sprayed upon and adheres to the rotating tube at and around the base of the fin, and upon the outer edges of the fin so that a sintered deposit of brazing alloy is applied to these portions throughout the entire finned length of the tube.

This manner of application of the brazing powder avoids any plugging of the brazing alloy between fins which might occur by dipping or painting. In cases where the fin is copper clad material, it is especially important that any free or exposed copper edge be sealed. For this purpose the metallic brazing alloy powder is deposited by the torch on the outer edge of the clad fin, and, if necessary to promote adherence, the outer edge of the clad fin may be roughened, as by shot or grit blasting, or by a knurled roller or the like, so that the sintered deposit of brazing alloy will adhere thereto.

The finned tube, with brazing alloy deposited thereon in this manner, is then heated to brazing temperature in a special atmosphere brazing furnace to cause the brazing alloy to flow into all fine crevices between the tube and fin, and to flow upward around the base portions of the fin, and over the outer edge of the fin, forming a tight, unbroken bond between the tube and the fin, and also a protective coating sealing and protecting the outer edge of the fin with a securely bonded deposit of brazing alloy.

Having thus described the invention in general terms, by way of example an embodiment of the invention is illustrated in the accompanying drawing forming a part hereof, wherein like numerals indicate similar parts throughout the several views, and in which;

Fig. 1 is a diagrammatic front elevation of a lathe upon which the invention may be performed;

Fig. 2 is a top plan view of the lathe shown in Fig. 1;

Fig. 3 is an enlarged, fragmentary, sectional view of a portion of a finned tube showing the sintered deposit of brazing alloy applied to the tube at the base portions of the fin and also upon the outer edges of the fin;

Fig. 4 is a fragmentary, sectional view of a further enlarged portion of the finned tube shown in Fig. 3, showing the brazing alloy flowed outward upon the fin and into crevices between the fin and tube, after the furnace brazing operation;

Fig. 5 is a view similar to Fig. 4, of a slightly modified form of the finned tube after the furnace brazing; and,

Fig. 6 is a greatly enlarged fragmentary, sectional view through the tip or outer edge portion of a clad fin showing the manner in which the same is sealed and protected by a coating of brazing alloy.

Referring first more particularly to Figs. 1 and 2, the lathe upon which the invention may be carried out comprises generally the bed **10** having head stock **11** at one end provided with a rotatable chuck **12** of conventional design, adapted to be rotated in a usual and well known manner by conventional gearing and the like (not shown) driven by any suitable power means.

The tail stock **13** is mounted at the other end of the lathe, and a tool post **14** is mounted for longitudinal movement upon the bed of the lathe by the usual lead screw (not shown) coordinated with the mechanism which rotates the chuck in the head stock, as in usual practice.

The lathe differs from conventional lathe construction only in that a torch indicated at **15** is substituted upon the tool post **14** instead of the usual tool. The torch is of the type into which powdered metal may be blown by compressed air through an oxyacetylene flame causing the metal to be heated and deposited on the work in a sintered state.

The finned tube to be brazed comprises the tube, indicated generally at **16**, which may be formed of stainless steel, ferrous metal, nickel, Inconel or the like and upon which is spirally wound a fin, indicated at **17**, which may be formed of copper clad with stainless steel, or the fin may be formed of ferrous metal, nickel or Inconel.

As shown in Figs. 3 and 4, the base portions of the fin may be located in a spiral groove **18** formed in the peripheral surface of the tube **16**, into which the fin is wound under stress, or, as shown in Fig. 5, the fin **17** may be spirally wound, under tension, around the peripheral surface of the tube.

These spiral fins are stressed and stretched as they are spirally wound under tension around the tube, the stress holding the fin upon the tube. It is evident that if the fin stress is released, the bond between the fin and tube will be at least partially, if not entirely destroyed. These conditions may be aggravated in use by a differential in expansion of the two materials.

In either case, there will be fine crevices between the base portions of the fin and the tube. It is highly desirable that the brazing alloy when heated should flow into these fine crevices in order to insure a secure tight bond at these points so as to provide proper heat conductivity between the fin and tube when used in a heat exchanger, as well as to resist the corrosive action of fluids to which the finned tube may be subjected in use.

Heretofore, it has not been possible to satisfactorily flow brazing alloy into such fine crevices, and as a result a tight bond could not be obtained and maintained between the tube and the base portions of the fin.

I have discovered that by heating the tube and fin and immediately applying a sintered deposit of brazing alloy thereto, that the powdered metallic brazing alloy would adhere to these heated surfaces, and when the finned tube was subsequently heated in a brazing furnace, the deposited alloy would melt and flow into fine crevices, producing a tight bond between the tube and the base portions of the fin.

After the fin has been attached to the tube, the finned tube is mounted in the lathe, between the head stock and tail stock as shown in Figs. 1 and 2, with the tool post located in the starting position, adjacent to the left hand end of the finned portion of the tube, as viewed in Figs. 1 and 2.

The torch **15** is operated, without the application of powdered metal, so as to direct the flame upon the finned tube, and the lathe mechanism is started to rotate the finned tube and simultaneously move the tool post carrying the torch toward the right as viewed in Figs. 1 and 2, heating the tube and fin to desired temperature.

When the torch reaches a position spaced from the starting end, approximately such as shown in full lines in Figs. 1 and 2, the tool post is backed up to the starting point and powdered brazing alloy is fed to the torch.

The lathe is then operated to rotate the finned tube and continuously move the tool post, carrying the torch, toward the right, depositing sintered brazing alloy upon the tube **16** adjacent to the base of the fin as indicated at **19** in Fig. 3 and also upon the outer edge of the fin as indicated at **20**, the sintered alloy adhering to the heated surfaces of the tube and fin.

The sintered brazing alloy is thus deposited upon the hot surfaces of the tube and fin, and, as the torch continues to move toward the right, each successive portion of the tube and fin will be heated by the torch flame ahead of the brazing alloy applied thereto, so that the sintered alloy will adhere to the tube at and around the base of the fin, and to the outer edge of the fin, throughout the length thereof.

Thus, all portions of the tube and fin, from one end thereof to the other, will be heated to the necessary temperature before the brazing alloy is deposited thereon, thus causing the sintered alloy to adhere to the tube and fin material, even though the fin material is very thin, say .008″ in thickness and spaced say 20 to 30 convolutions per inch of tube length. Moreover, the deposit of the brazing powder in this manner avoids any plugging of the extremely narrow spaces between fin convolutions.

In Fig. 6 is shown a greatly enlarged section of the outer edge or tip portion of a stainless steel clad copper fin, showing the manner in which the brazing alloy deposited upon the outer edge of the fin seals and protects the copper.

The copper fin is indicated at **21** and the stainless steel clad upon each side thereof is indicated at **22**. As shown in Fig. 3, the brazing alloy **20** deposited upon the outer edge of the fin entirely covers and seals the edge of the copper fin **20** and extends over the edges of the stainless steel clad layers **22**.

The outer edges of these stainless steel layers may be slightly rounded, as shown at **23**, causing the brazing alloy deposit to flow downward thereover at each side of the fin, during the furnace brazing operation, thus completely sealing and protecting the copper.

In order to assure adherence of the deposit of brazing alloy to the outer edge of the fin, the outer edge may be roughened by shot or grit blasting, knurling or the like. If desired, the tube surfaces may be similarly roughened so as to assure adherence of the brazing alloy thereto adjacent the base of the fin.

The brazing alloy may be a commercial alloy of suitable composition including elements such as nickel, chromium, iron, silicon and boron. After the brazing alloy has been deposited upon the tube at the base of the fin, and upon the outer edge of the fin, as shown in Fig. 3, in the manner above described, the brazed finned tube is then furnace brazed, with brazing temperatures and atmospheres appropriate to the type of alloy being used.

This furnace brazing is carried out at a temperature above the flow point of the brazing alloy but below the melting point of the copper in the fin so as to cause the brazing alloy to flow upward or outward upon the base portion of the fin, as indicated at **24** in Figs. 4 and 5, and into all fin crevices between the fin and the tube such as the grooves **18** in Fig. 4 and the crevices **25** between the base of the fin and the tube in Fig. 5. The fin will thus be tightly bonded to the tube at all points throughout its length.

As above pointed out, in finned tubes of this character the fin is held onto the tube because the fin material is stressed as it is wound onto the tube. If the fin stress is released the bond between the fin and the tube becomes less sure. Differential in expansion of the materials may aggravate this condition. By applying the brazing alloy in the manner above described, a sure bond between the fin and the tube is obtained and maintained under working conditions.

Although the invention has been illustrated and described in detail as applied to the manufacture of finned tubes with fins spirally wound thereon, it should be understood that tubes having fins extending longitudinally thereof may be brazed in the same manner.

In the foregoing description, certain terms have been used for brevity, clearness and understanding, but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such words are used for descriptive purposes herein and are intended to be broadly construed.

Moreover, the embodiments of the improved construction illustrated and described herein are by way of example, and the scope of the present invention is not limited to the exact details of construction.

Having now described the invention or discovery, the construction, the operation, and use of preferred embodiments thereof, and the advantageous new and useful results obtained thereby; the new and useful construction, and reasonable mechanical equivalents thereof obvious to those skilled in the art, are set forth in the appended claims.

I claim:

1. The method of making finned tubes for heat exchangers of a type including a corrosion-resistant tube having high-temperature strength and fin ribbon means bonded thereto formed of high-heat-conductivity material having corrosion-resistant surfaces, which includes the steps of providing a stainless steel tube; securing copper ribbon fin means having stainless steel clad to both ribbon surfaces of the fin, to the exterior of the tube with the base edge of the fin ribbon in contact with the tube and with copper exposed at the outer edge of the fin ribbon; rotating the tube with the fin means secured thereon on its axis; initially preheating one end of the rotating tube and fin means; directing a flame and a spray of heated powdered metallic brazing alloy simultaneously against the heated end of the rotating tube and fin means; moving the flame and spray axially of the rotating tube and fin means from said heated end to the other end of the tube; such directing and moving of the flame and spray with respect to the rotating tube and fin means preheating successive unheated tube and fin means portions beyond the initially preheated rotating one end of the tube and fin means and ahead of the spray; progressively applying, by said directed and moving spray, an adherent deposit of heated powdered alloy metal on the heated tube at and around the base edge of the fin ribbon and on the copper exposed outer edge of the fin ribbon throughout the length of the rotating tube and fin means; furnace heating the tube and fin means with the adherent deposit thereon to brazing temperature; melting the adherent deposited alloy, by said furnace heating, and flowing the melted alloy outward on the fin surfaces from the base edge of the fin and also along the contacting interface surfaces of the base edge of the fin and tube and also over the outer edge of the fin; and the melted and flowed alloy metal forming a tight unbroken bond between the tube and fin means and protecting and sealing the outer exposed copper edge of the fin means.

2. The method of making finned tubes for heat exchangers of a type including a corrosion-resistant tube having high-temperature strength and fin ribbon means bonded thereto formed of high-heat-conductivity material having corrosion-resistant surfaces, which includes the steps of providing a stainless steel tube; spiralling winding a copper ribbon having stainless steel clad on both ribbon surfaces around the tube under tension to hold the

fin upon the tube with the base edge of the fin ribbon in contact with the tube and with copper exposed at the outer edge of the fin ribbon; rotating the tube with the spiral fin held thereon on its axis; initially preheating one end of the rotating tube and fin; directing a flame and a spray of heated powdered metallic brazing alloy simultaneously against the heated end of the rotating tube and fin; moving the flame and spray axially of the rotating tube and fin from said heated end to the other end of the tube; such directing and moving of the flame and spray with respect to the rotating tube and fin preheating successive unheated tube and fin portions beyond the initially preheated rotating one end of the tube and fin and ahead of the spray; progressively applying, by said directed and moving spray, an adherent deposit of heated powdered alloy metal on the heated tube at and around the base edge of the fin ribbon and on the copper exposed outer edge of the fin ribbon throughout the length of the rotating tube and fin; furnace heating the tube and fin with the adherent deposit thereon to brazing temperature; melting the adherent deposited alloy, by said furnace heating, and flowing the melted alloy outward on the fin surfaces from the base edge of the fin and also along the contacting interface surfaces of the base edge of the fin and tube and also over the outer edge of the fin; and the melted and flowed alloy metal forming a tight unbroken bond between the tube and fin and protecting and sealing the outer exposed copper edge of the fin.

3. The method of making finned tubes for heat exchangers of a type including a corrosion-resistant tube having high-temperature strength and fin ribbon means bonded thereto formed of high-heat-conductivity material having corrosion-resistant surfaces, which includes the steps of providing a corrosion-resistant tube; securing fin ribbon means formed of high-heat-conductivity material having corrosion-resistant surfaces to the exterior of the tube with the base edge of the fin ribbon in contact with the tube and with the high-heat-conductivity fin material exposed at the outer edge of the fin ribbon; rotating the tube with the fin means secured thereon on its axis; initially preheating one end of the rotating tube and fin means; directing a flame and a spray of heated powdered metallic brazing alloy simultaneously against the heated end of the rotating tube and fin means; moving the flame and spray axially of the rotating tube and fin means from said heated end to the other end of the tube; such directing and moving of the flame and spray with respect to the rotating tube and fin means preheating successive unheated tube and fin means portions beyond the initially preheated rotating one end of the tube and fin means and ahead of the spray; progressively applying, by said directed and moving spray, an adherent deposit of heated powdered alloy metal on the heated tube at and around the base edge of the fin ribbon and on the exposed outer edge of the fin ribbon throughout the length of the rotating tube and fin means; furnace heating the tube and fin means with the adherent deposit thereon to brazing temperature; melting the adherent deposited alloy, by said furnace heating, and flowing the melted alloy outward on the fin surfaces from the base edge of the fin and along the contacting interface surfaces of the base edge of the fin and tube and also over the outer edge of the fin; and the melted and flowed alloy metal forming a tight unbroken bond between the tube and fin means and protecting and sealing the outer exposed edge of the fin means.

4. The method of making finned tubes for heat exchangers of a type including a corrosion-resistant tube having high-temperature strength and fin ribbon means bonded thereto formed of high-heat-conductivity material having corrosion-resistant surfaces, which includes the steps of providing a heat-resistant metal tube, securing fin ribbon means formed of high-heat-conductivity material to the exterior of the tube with the base edge of the fin ribbon in contact with the tube; rotating the tube with the fin means secured thereon on its axis; initially preheating one end of the rotating tube and fin means; directing a flame and a spray of heated powdered metallic brazing alloy simultaneously against the heated end of the rotating tube and fin means; moving the flame and spray axially of the rotating tube and fin means from said heated end to the other end of the tube; such directing and moving of the flame and spray with respect to the rotating tube and fin means preheating successive unheated tube and fin means portions beyond the initially preheated rotating one end of the tube and fin means and ahead of the spray; progressively applying, by said directed and moving spray, an adherent deposit of heated powdered alloy metal on the heated tube at and around the base edge of the fin ribbon throughout the length of the rotating tube and fin means; furnace heating the tube and fin means with the adherent deposit thereon to brazing temperature; melting the adherent deposited alloy, by said furnace heating, and flowing the melted alloy outward on the fin surfaces from the base edge of the fin and also along the contacting interface surfaces of the base edge of the fin and tube; and the melted and flowed alloy metal forming a tight unbroken bond between the tube and fin means.

5. The method of making finned tubes for heat exchangers of a type including a corrosion-resistant tube having high-temperature strength and fin ribbon means bonded thereto formed of high-heat-conductivity material having corrosion-resistant surfaces, which includes the steps of providing a stainless steel tube; securing copper ribbon fin means having stainless steel clad to both ribbon surfaces of the fin, to the exterior of the tube with the base edge of the fin ribbon in contact with the tube and with copper exposed at the outer edge of the fin ribbon; rotating the tube with the fin means secured thereon on its axis; directing a flame and a spray of heated powdered metallic brazing alloy simultaneously against one end of the rotating tube and fin means; moving the flame and spray axially of the rotating tube and fin means from said one end to the other end of the tube; such directing and moving of the flame and spray with respect to the rotating tube and fin means preheating successive unheated tube and fin means portions ahead of the spray; progressively applying, by said directed and moving spray, an adherent deposit of heated powdered alloy metal on the tube heated by said flame at and around the base edge of the fin ribbon and on the copper exposed outer edge of the fin ribbon throughout the length of the rotating tube and fin means; furnace heating the tube and fin means with the adherent deposit thereon to brazing temperature; melting the adherent deposited alloy, by said furnace heating, and flowing the melted alloy outward on the fin surfaces from the base edge of the fin and also along the contacting interface surfaces of the base edge of the fin and tube and also over the outer edge of the fin; and the melted and flowed alloy metal forming a tight unbroken bond between the tube and fin means and protecting and sealing the outer exposed copper edge of the fin means.

6. The method of brazing a finned tube with a brazing alloy which consists in rotating the finned tube on its axis, directing a flame upon one end of the rotating finned tube, moving the flame axially of the rotating tube to a point spaced from said one end thereby preheating the tube from said one end to said point, returning the flame to said one end, directing said flame and a spray of heated metallic brazing alloy powder simultaneously against the heated tube at said one end, moving the flame and heated powder spray axially of the rotating tube to the other end of the tube thereby preheating successive portions of the finned tube ahead of the spray and depositing heated powder on the heated tube as an adherent metal coating adjacent the base of the fin progressively throughout the length of the heated finned tube, and then furnace heating the finned tube to brazing temperature and thereby melting and flowing the adherent deposited metal along the fin

surfaces at the base of the fin and into interface crevices between the tube and fin.

7. The method of brazing a finned tube with a brazing alloy which consists in rotating the finned tube on its axis, directing a flame upon one end of the rotating finned tube, moving the flame axially of the rotating tube to a point spaced from said one end thereby preheating the tube from said one end to said point, returning the flame to said one end, directing said flame and a spray of heated metallic brazing alloy powder simultaneously against the heated tube at said one end, moving the flame and heated powder spray axially of the rotating tube to the other end of the tube thereby preheating successive portions of the finned tube ahead of the spray and depositing heated powder on the heated tube as an adherent metal coating adjacent the base of the fin and upon the outer edge of the fin progressively throughout the length

of the heated finned tube, and then furnace heating the finned tube to brazing temperature and thereby melting and flowing the adherent coating metal along the fin surfaces at the base of the fin and into interface crevices between the tube and fin and over and around the outer edge of the fin.

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