Aug. 29, 1961 J. F. BARNES ET AL 2,998,339

PRODUCTION OF TUBES AND STRUCTURAL SHAPES FROM METAL FOILS

Filed Dec. 23, 1955

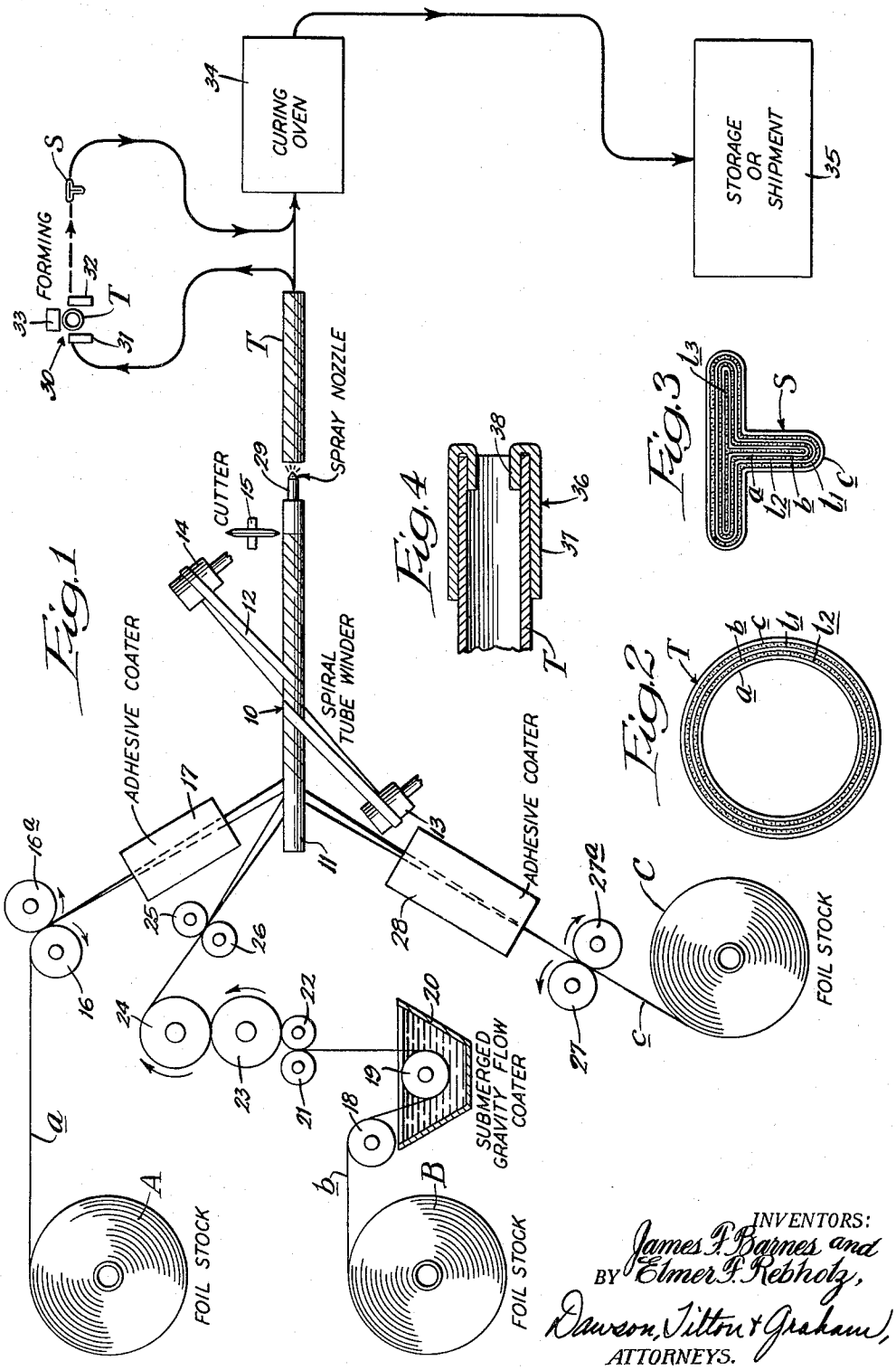


Fig. 1

Fig. 2

Fig. 3

Fig. 4

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United States Patent Office 2,998,339
Patented Aug. 29, 1961

2,998,339

PRODUCTION OF TUBES AND STRUCTURAL SHAPES FROM METAL FOILS

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Filed Dec. 23, 1955, Ser. No. 555,069
2 Claims. (Cl. 154—83)

This invention relates to the production of tubes and structural shapes from metal foils.

The present application is a continuation-in-part of our co-pending application Serial No. 532,189, filed September 2, 1955, now Patent 2,954,803. Reference is also made to applicants' co-pending application Serial No. 462,010, filed October 13, 1954, now abandoned.

Broadly stated, the object of the present invention is to provide a novel method for producing tubes and structural shapes from metals, and at the same time producing various new products. In accordance with the present invention, metal foils are combined to form tubes and structural shapes. One of the advantages of this procedure is that the resulting tubes and structural shapes have greater strength in relation to weight than if they were formed of solid metal. Another important advantage relates to the ease of fabrication of the tubes and structural shapes. The method of this invention and the products obtained thereby can provide the means for considerable cost savings in the production of tubes and structural shapes which have substantially the same uses and advantages of tubes and structural shapes heretofore produced entirely from metals. By the method of this invention the tubes and structural shapes will contain a substantially reduced amount of metal, savings of 20 to 40% in metal content being obtainable. A related advantage arises from the relative lightness of the products as compared with similar products of solid metal. This invention also permits a wide variation in the properties of the tubes and structural shapes. In this connection, one important advantage for certain uses is that the products can contain a number of different kinds of metal foils, making possible the production of pipe, for example, which has a high resistance internally to corrosion while otherwise being formed of rather inexpensive, non-corrosion resistant materials. Further objects and advantages will appear as the specification proceeds.

The present invention, in both its product and method aspects, is illustrated in the accompanying drawing, in which—

FIGURE 1 is a diagrammatic showing of a method for producing tubes and structural shapes in accordance with the present invention; FIG. 2, a cross-sectional view of a tube produced in accordance with the method of FIG. 1; FIG. 3, a cross-sectional view of a T-shaped structural member produced in accordance with the method of FIG. 1; and FIG. 4, a fragmentary longitudinal sectional view of a tube produced in accordance with the present invention and having an end cap applied thereto.

Looking first at FIG. 1, there is illustrated a processing line for the production of various products in accordance with this invention, including tubes and structural shapes. In the central portion of the sheet is shown a conventional spiral tube winder **10**, which includes as principal elements a stationary mandrel **11**, looped winding belt **12**, driving pulley **13**, driven pulley **14**, and cutter **15**. As shown, one side of belt **12** forms a single loop around mandrel **11**, as is well known in the art. In practicing the present invention, a plurality of sheets of metal foil are fed into winder **10** under the loop in belt **12** so that the sheets are wound around mandrel **11** to form a hollow tube. During the winding operation, the sheets are

adhesively united, which permits the tube as it is advanced along mandrel **11** to be cut into segments by cutter **15**. In the illustration given, a sheet of foil *a* is fed from foil stock roll A through rollers **16** and **16***a* and adhesive coater **17** to winder **10**. At the same time, a sheet of foil *b* is drawn off of stock roll B, passing over roller **18** and under roller **19**, which runs within an adhesive bath **20**. After foil sheet *b* has been coated on both sides within bath **20**, it is drawn upwardly between presser rolls **21** and **22** and around distribution rolls **23** and **24** to be passed to mandrel **11** through feed rolls **25** and **26**. Still another sheet of foil *c* is unwound from stock roll C by feed rolls **27** and **27***a* and passed through adhesive coater **28** to mandrel **11**. As illustrated, the production line is set up for producing a 3-ply tube, which if desired can then be formed into other structural shapes, as will subsequently be described in detail. The foil sheet *a* will be the innermost ply, providing the interior walls of the tube, and will be usually adhesively coated only on the side adjacent sheet *b*. Sheet *b* will be adhesively coated on both sides to form the intermediate ply. Sheet *c* comprises the outer ply which provides the outer surface of the tube, and usually is coated only on its inside surface. In the winding operation, all of these plies are brought together under pressure by the action of belt **12** against mandrel **11**. The adhesive coating on both sides of intermediate sheet *b* and on the adjacent sides of sheets *a* and *c* provides for the desired adhesive bonding.

It is desirable that means be provided for controlling and limiting the thickness of the adhesive coating between the metal foil sheets. In one preferred embodiment, each layer of adhesive in the tube has a thickness less than the combined thickness of the foil sheets which it unites. However, somewhat thicker adhesive layers may give satisfactory results for some purposes. The adhesive coating apparatus shown in the drawing can be described as a submerged gravity flow coater. The adhesive is contained within bath **20** as a solvent solution, which is applied to both sides of sheet *b* as it passes around roll **19** within the bath. The sheet is then drawn upwardly, preferably along a vertical line, so that the excess adhesive solution will run downwardly along both sides of sheet *b* and back into bath **20**. During this interval, solvent is also evaporating from the adhesive, and it tends to achieve a uniform tacky condition as it passes between rolls **21** and **22**, which act to press the adhesive coating into smooth layers of uniform thickness. Preferably, rolls **21** and **22** are made adjustable with respect to each other so that the spacing therebetween can be closely controlled. Rolls **23** and **24** act as distribution rolls to obtain a final evening and smoothing of the adhesive layers. These rolls should also be adjustable with respect to each other and with respect to roll **22**. It will be noted that rolls **21**, **22**, **23** and **24** have been designed so that each side of sheet *b* receives substantially the same amount and type of contact. This is definite advantage in obtaining coatings of equal and uniform thickness on both sides of sheet *b*.

Continuing with FIG. 1 of the drawing, after being severed by cutter **15**, the tube T can be further processed in several different ways. In one preferred embodiment, an adhesive coating is deposited on at least part of the inner walls of the tube. For example, this can be done by providing the outer end of mandrel **11** with a spray nozzle **29**, which is supplied with a liquid adhesive through passages within mandrel **11**, or by other suitable means. After the interior walls of the tube T have been coated with adhesive, the tube can be passed to a forming operation at **30**. The purpose of the forming operation is to change the cross-sectional shape of the tube, which

in the illustration given was circular as formed on mandrel 11. In the forming operation, not only is the cross-sectional shape of the tube altered, but also at least part of the inner walls of the tube are brought together in adhesively-bonded relation. In the illustration given, the interiorly coated tube T is collapsed upon itself to form a cross-sectional shape of reduced volume. This may be accomplished by cooperating presser elements 31, 32 and 33 or by other suitable means. For example, the presser elements may cooperate to produce a structural member such as the T-shaped member S. The appearance in cross-section of tube T is shown more clearly in FIG. 2, as is that of the resulting structural member S in FIG. 3. Looking first at FIG. 2, the inner foil layer *i* is bonded to the intermediate foil layer *b* by adhesive layer l_2, while the outer foil layer *c* is bonded to the inner foil layer *b* by adhesive layer l_1. The respective foil and adhesive layers are similarly designated in FIG. 3, except that an additional adhesive layer l_3 has been added. This layer is produced by the adhesive which is sprayed into the interior of tube T.

The formed shape S and/or the tube T can be passed through a curing oven 34 before being passed to storage or shipment at 35. With certain types of adhesives, such as the thermoplastic adhesives, curing oven 34 can be omitted. However, with the preferred adhesives of the thermosetting type, it is desirable to have the adhesive in the so-called B-stage, where it is still flowable under heat and pressure, during the forming operation. Subsequently, the adhesive can be cured to the infusible or C-stage in curing oven 34. In other words, the adhesive should be in a plastic condition for best results in forming the tubes. Resins suitable to "B" staging include phenolics modified with polyvinyl butyral, polyvinyl formal acrylo-nitrate, and nylon. Epoxy resins can be used with curing agents such as metaphenylene diamine, dicyandi-amide and other curing agents capable to "B" staging.

In some applications, tubes and structural shapes produced in accordance with this invention may have a tendency to delaminate at the ends thereof. This can be overcome by applying end caps to the tubes and structural shapes. For example, the end portion of tube T, as shown in FIG. 4, has a crimped cap 36 applied thereto. Cap 36 has a tubular portion 37 encircling the outside of end portion of tube T, and is brought over the end of tube T and provided with an inwardly extending annular flange portion 38. Cap 36 can be secured to tube T by means of a pressed fit, and the crimping of flange portion 38 against the inner walls of tube T. However, if desired, cap 36 can be adhesively bonded to tube T. Where it is desired to use the tubes in applications requiring threaded connections, the outside of cap 36 can be provided with the appropriate threads. Various other types of caps and end covers can be used for reinforcement and prevention of delamination.

Any of the commercially available metal foils can be used in producing tubes and structural shapes according to the present invention. These include aluminum, lead, tin, Inconel, stainless steel, copper, titanium, etc. Aluminum foil is preferred, however, because of its relative cheapness at the present time. Generally, aluminum foil and other metal foils range in thickness from as low as .25 mil to as great as 5 mils. Both annealed and hard aluminum foils can be used. For example, hard and soft aluminum foils can be combined, or aluminum foil can be combined with other metal foils.

In uniting the metal foil sheets, it is preferred to wind the sheets about the mandrel in a spiral pattern, and to have at least the innermost and outermost foil sheets wound in edge-overlapping relation with respect to themselves. Butt winds can also be used for some purposes, especially for the inner layers of foil. The desired spiral winding can be carried out on conventional spiral tube winders, or other suitable equipment. Alternatively, products having desirable properties can be formed by winding the foil sheets in a convolute pattern, as would be obtained with a conventional convolute tube winder.

Various adhesive materials can be employed while still achieving some of the advantages of this invention. Generally, the adhesive should be selected for its capacity to form a strong bond with metals and particularly with aluminum. Suitable adhesives for some purposes include those falling within the classes of thermosetting resin adhesives, thermoplastic resin adhesives, and elastomeric adhesives. The thermosetting resin adhesives are preferred, and particularly the epoxy resin adhesives. Epoxy resin adhesives upon first application and when only partially cured are flexible and resilient, while being curable by the application of heat to a condition of increased rigidity. Moreover, such adhesives function as good bonding agents whether or not they are completely cured to a rigid, infusible condition. A wide range of properties can be achieved with regard to the product either in its final condition or for intermediate processing operations, as described above.

The epoxy resin adhesives can be applied in the form of liquids, solvent solutions, or for short periods of time as hot solutions (melts), or melted B-staged powders. The adhesive is shown being applied as a solvent solution in FIG. 1 of the drawing. When the adhesive is used in the form of a solvent solution, the components of the adhesive can be dissolved in a suitable solvent and this solution applied to the foil. If desired, the adhesive solution can be applied to one surface of a foil sheet and the solvent evaporated therefrom before the second sheet is applied.

The advantages of using epoxy resins include excellent adhesion to clean metal surfaces without complicated surface preparations. The hardening (or polymerization) mechanism is one of addition rather than condensation. This means that no by-products are formed to interrupt the long chain formations. These can be manifested in the formation of gaseous pockets. Pressure must be employed to prevent this inlaminates using condensation polymerized products, while only a minimum or contact pressure is adequate to produce a good epoxide film. Another advantage of this mechanism is the low shrinkage factor that does not tend to distort the desired structural dimensions.

One particularly suitable adhesive consists of the reaction product of an epoxy resin and a polyamide. These components can be heated individually to a temperature of 90 to 100° C. to soften them, then mixed and applied. Reaction between the two components gives a cross-linked polymer having characteristics of hardness and flexibility and curing time which vary with the mixing proportions and temperature of curing. The epoxy resins and the polyamide components can be of the types described in our co-pending application Serial No. 462,010. Usually about a 50–50 mixture of epoxy resin and polyamide gives good results. These components can be dissolved in methylethyl ketone or toluene, xylene, or comparable solvents for application as solvent solutions. However, the preferred adhesives for this invention are not limited to those prepared from the interaction of epoxy resins and polyamides. They may also be made by reacting epoxy resins with amine hardeners and cross-linging agents. These in the main are polyamines of various molecular weights as ethylenediamine, phenylenediamines, etc. Mixtures of polyamide and diamines can also be used.

Thermosetting resin adhesives of the character described are quite desirable for applicants' purposes. However, as indicated, for some applications, thermosetting resin adhesives or elastomeric adhesives might be used. Such adhesives are usually either flexible or rigid upon application, and lack the range of flexibility-hardness properties of epoxy resin adhesives. For example, rubber base adhesives remain flexible, while thermoplastic resin

adhesives like polystyrene adhesives are rigid at normal temperatures, although softening on the application of heat. Further, such adhesives are normally unstable in the higher temperature regions, say in excess of 200° F. Some resins, however, such as the phenolic resins, are useful for increasing heat resistance and dimensional stability of the laminate products under heat. Epoxy resins containing amine hardeners have improved stability to heat, while those containing polyamides have better low temperature flexibility characteristics.

The preference for epoxy resin adhesives, as indicated above, is based in part on the range of properties obtainable with these adhesives. By combining the epoxy resin with the long-chain polyamides in various proportion, the flexibility of the adhesive can be changed over a considerable range. The inclusion of low molecular weight hardeners, like ethylenediamine in amounts up to 10% by weight of the mixture, tends to reduce the flexibility of the adhesive. Additional modifying resins can also be included. Inert fillers may also be used for various purposes. Fillers like calcium carbonate, aluminum oxide, and aluminum powder increase the rigidity and decrease the shrinkage of the adhesive layer. The metal powder increases the heat transfer. Fillers like asbestos or glass fibers can be used. The asbestos fibers would increase the heat resistance, while the glass fibers would increase the strength of the adhesive layer. Other types of fillers or inner layers can also be used, such as resin impregnated cloth, paper, etc.

As indicated above, the adhesive formulation, especially in the case of thermosetting resin adhesives like the epoxy resin adhesives can be employed as a means for varying the properties of the tubes and structural shapes. The properties of the tube walls can also be varied by increasing or decreasing the thickness of the foil or by selecting foil which has been tempered to a different degree of hardness and flexibility. The thickness of the adhesive layers between the foil layers will also affect the properties. In general, the thicker the foil layer, the more rigid and less flexible will be the resulting material. Also, as already indicated, the difference between merely letting the adhesive set at ordinary temperatures and subjecting it to a heat-cure of greater or lesser duration can be taken advantage of to control the relative flexibility or rigidity of the resulting material.

As a specific example, following the general method described in connection with FIG. 1, three sheets of annealed aluminum foil of 3 mils thickness are fed into a spiral winder of a standard commercial type and wrapped to form a multi-layered tube. The inner foil layer was coated on both sides with an adhesive solution, which was formed in the following way. Sixty parts by weight of an epoxide resin having an epoxide equivalent of 450 to 525 is dissolved in 30 parts of toluol and 30 parts of methylethyl ketone. A second mixture is formed from 32 parts of a condensation product of dilinoleic acid and ethylene diamine, 11 parts toluol, and 3 parts butanol. 120 parts of the first mixture combined with 46 parts of the second mixture to form an epoxy resin adhesive solution containing 55.4% solids. This adhesive was used as is, but it can be thinned to a different consistency with a mixture of 5 parts toluol and 1 part butanol. If faster drying is desired, additional quantities of methylethyl ketone can be added. In the 55.4% solids concentration, the adhesive mixture has a pot life in excess of 12 hours and this can be increased by adding additional quantities of solvent. Polyamide 115 is a condensation product of dilinoleic acid and ethylenediamine produced by General Mills.

After the tube had been formed, it was heat-cured at 300° F. for 10 minutes to achieve the optimum physical properties. Alternatively, samples of the tube were air-cured at room temperature for several minutes and then subjected to a forming operation. Preparatory to the forming operation, the interiors of the tubes were sprayed with an adhesive solution formulated as just described. The tubes are then collapsed under pressure to form a member which was T shaped in cross-section, and then heat-cured at 300° F. for 10 minutes.

As a specific example of a phenolic thermosetting resin adhesive which can be used in practicing the present invention, the following is illustrative. One hundred parts of a phenol formaldehyde resin dissolved in methanol (64–68% solids) is combined with 100 parts by weight of a 10% solution of polyvinyl butyral resin in methylethyl ketone.

In another variation of the specific example set forth, a .5 mil sheet of stainless steel foil or other corrosion-resistant foil such as Inconel or titanium foil, can be substituted for the innermost or outermost sheet of aluminum foil in the procedure described above. Where a tube is desired for use in conveying liquids which provide a corrosion problem, it will be desirable to have the inner layer of the tube composed of a corrosion-resistant foil, while at the same time avoiding the high cost of having the entire tube formed of the corrosion-resistant metal. Similarly, structural shapes which are corrosion resistant can be obtained by using a corrosion-resistant foil as the outer sheet of the tube, which will then provide the only exposed surface after the collapsing of the tube to form the structural shape. In addition to T-shaped members, various other structural shapes can readily be produced, such as members which are L-shaped, H-shaped, I-shaped, etc., when viewed from the end or in cross-section. Also, for some purposes, it may be desirable to collapse the tubes to form flat structural members. In addition to forming the tubes in suitable molds by applying pressure to the outside thereof, the tubes may be formed by placing a form section in the center of the tube and molding against it.

In making a tube or pipe that should have corrosion-resistance on the inside for transmitting liquid or gases, a stainless steel liner can be used. For example, a sturdy two inch diameter pipe with internal corrosion resistance can be built up in accordance with the method of this invention from the following plies in order from inside out: 2 mil dead soft stainless steel (300 series), a 5 mil annealed A1 aluminum foil, followed by three 5 mil hard A1 aluminum foils. For ease in handling the normally "springy" stainless steel foil, it can first be laminated to the annealed aluminum foil. This forms a unit that can be wrapped as a single ply around the mandrel. The additional three plies can then be added as indicated. For making structural members like an I-beam, resistance to corrosion on the outside may be desired. This can be readily accomplished by reversing the order of wrapping of the foils for the tube or pipe just described, and then forming the tube into the I-beam shape, as described previously in this application.

For certain structural shapes where it is desired primarily to employ aluminum foils, it may be desirable to use alternating foils of hard and annealed stock. The inclusion of soft foil facilitates the forming of the structure or unit from the tube. The hard foil gives it the required rigidity and tensil strength. It is preferable if the hard foil is on the outside, so that the surface is more mar-proof. For specialized high-resistant, light-weight pipes, tubing or structural members, it may be desirable to use titanium and stainless steel foils. These could be combined with a heat-resistant phenolic resin or with a high temperature adhesive like butyl titanate. Phenolics, alkyds, silicons and epoxy resins can be modified with butyl titanate to give desirable characteristics. Other alkyl titanates can be used but the butyl is at present the most readily available. Structural members that must resist chemicals common to the food industry can use Inconel on the outside. This is desirable because Inconel is resistant to cleaning compounds used to make food processing enclosures and equipment free of bacteria and fungi. As a further modification, a thin perforated sec-

tion of material can be used as the core for the structural state. For example, a thin perforated laminated phenolic I-beam can be placed in the center of the tube, and the tube collapsed around the I-beam so as to cover the phenolic core.

To further clarify the present invention, it is desired to point out that while metal to metal bonding is generally an old art, it has heretofore been used as a fastening or anchoring device or technique, which does not change, alter, or modify the characteristics of the units being bonded. On the other hand, the proximity bonding of this invention relates to the art of taking two or more thin, metallic sheets or stirps of similar or dissimilar metal and bonding them together to yield a product which has the characteristics and properties different from the sum total of each of the components.

While in the foregoing specification, this invention has been described with reference to preferred embodiments thereof and many details have been set forth for purpose of illustration, it will be apparent to those skilled in the art that the invention is susceptible to other embodiments and that many of the details described herein can be varied widely without departing from the basic concepts of the invention.

We claim:

1. The method of producing structural shapes from metal foils, comprising winding a plurality of sheets of metal foil around a mandrel while adhesively uniting said sheets to form a hollow tube, depositing an adhesive coating on at least part of the inner walls of said tube, and applying pressure to the outside walls of said tube in such a way as to alter its cross-sectional shape and to bring together in adhesively-bonded relation at least part of the adhesive coated inner walls of said tube.

2. The method of producing structural shapes from metal foils, comprising winding a plurality of sheets of metal foil in a spiral pattern around a mandrel with an adhesive material distributed between said sheets, uniting said spirally-wound sheets by means of said adhesive material to form a hollow tube, separating said tube from said mandrel, spraying a liquid adhesive into said tube to coat the inside thereof, and collapsing the internally-coated tube upon itself to form a cross-sectional shape of reduced volume, at least part of the coated inner walls of said tube being adhesively united to each other.

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