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MANUFACTURE OF FLEXIBLE CORRUGATED METALLIC WALLS.

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This invention relates to the manufacture of highly-flexible deeply-corrugated tubular metallic walls.

Walls of this character are now applied to a great variety of uses which require that they possess to a high degree the characteristics of elasticity of form and uniformity of action, and also of great durability of performance, under repeated stress. In many uses to which they are put, as in thermostats for example, a relatively large elastic range of movement is required to ensure that the wall shall return to its original form and length, without taking a permanent set, after the deforming force has been removed; and the importance of this elasticity of form of the wall as a whole, as contrasted with the elastic limit of the metal of which it is composed, becomes apparent when it is remembered that walls of this character are frequently called upon to withstand a variation in axial length of twenty-five per cent, or even more, of their normal length, whereas the metal of which they are ordinarily made has per se an elastic limit of less than two per cent. In other uses to which walls of this character are put, as in pumps for example, great endurance, life or durability of performance is required, because the wall must withstand many millions of flexures, with their attendant alternations or repetitions of stress, without rupture.

Walls of the character herein considered are usually fabricated from tubes of relatively thin metal, having a thickness on the order of .010″ or less, by subjecting the tube to various cold working operations by which the tube is converted into the required deeply-corrugated form. The cold working of the metal, if not carried too far, has been found to impart life or durability, as well as resilience, to the finished wall; and experience has demonstrated the advisability of leaving in the completed wall the characteristics imparted thereto by a suitable amount of cold working, because if the wall, after it is brought to final shape, is subjected to a true annealing temperature, i. e., such a temperature as induces a marked change in grain growth, and restores or tends to restore the grains to equiaxed condition, the resultant product possesses a relatively low range of elastic action.

It has therefore been the practice in the manufacture of these walls to avoid all heat treatment after the final shaping of the metal, so that the elasticity and capacity to withstand repeated stress imparted to the metal by the cold working operations are left in the completed wall; and walls so manufactured have a relatively high elasticity of form and are capable of withstanding a great number of flexures before rupture.

I have discovered, however, that the desired characteristics of these cold-worked deeply-corrugated tubular metal walls can be further improved by subjecting the metal to a predetermined heat treatment after the forming operations; and it is an object of this invention to provide a method of manufacturing a wall of this character whereby its elastic performance is improved and its limit of elastic deformation is increased, so that the wall may be flexed to a greater extent without taking a permanent set, than has heretofore been possible with walls as heretofore made.

I have also discovered that improved elasticity of form or an increased range of elastic action can be obtained in the completed wall, and at the same time the wall can be stiffened, i. e. the modulus of elasticity of the wall, as a whole, can be increased, by subjecting the metal to a predetermined heat treatment after the forming operations, so that the ratio of deformation to load, or the degree of deformation for a given load, is decreased. It is a further object of this invention to provide a method of manufacturing a wall of this character whereby the wall may be thus stiffened without impairing its elastic performance.

Experience has also demonstrated that a highly-flexible deeply-corrugated tubular metal wall manufactured by the processes heretofore in use has a tendency to change its free overall length, or "creep", when subjected to stress under heat for a lapse of time, and this is undesirable because of the change in the normal position, or in the limits of stroke under a given applied stress, of the element or elements connected to or actuated by the wall. I have further discovered that the tendency of a wall of this character to increase its free overall length, or "creep", can be materially reduced, if not eliminated, by a predetermined heat treatment of the metal after the forming operations; and it is a further object of this invention to provide a

method of manufacturing walls of this character whereby the "creep", or tendency to increase in free overall length, may be substantially reduced or controlled within limits which largely eliminate the disadvantageous consequences heretofore incident to such tendency.

The life or durability of a highly-flexible deeply-corrugated tubular metal wall is influenced by many factors which are dependent upon the magnitude, the number and the widely varied character of the stresses and strains to which the different portions of the metal are subjected. Longitudinal or axial flexure of such a wall is accompanied not only by complicated bending stresses, but also by differential changes in the radial and circumferential dimensions of the peripheral elements of the expanding and contracting wall; and variation in external or internal pressures of the fluid confined by the wall also set up additional strains of axial and diametrical tension and compression. The unit magnitude of these strains depends upon the cross sectional area of the particular section to which the stress is applied; but my investigations have demonstrated the behavior of metals in thin curved sections, under stresses of a given unit magnitude, is in many respects quite different from that of a straight thicker section of the same metal when similarly treated. The endurance life of a uniformly thick piece of metal when subjected to repeated stresses within its elastic limit appears to be independent of that limit, but I have discovered that the capacity of a relatively-thin deeply-corrugated tubular metal wall to withstand stress, when subjected to repeated flexure either within or without its elastic range of action, can be increased by subjecting the wall, after the forming operations, to a predetermined heat treatment; and it is a further object of this invention to provide a method of producing walls of this character whereby the capacity of the wall to successfully withstand repeated applications of intermittent or alternating stress may be substantially improved.

Other objects will appear as the description of the invention proceeds.

The general purpose of this invention is, therefore, to provide a method of treating highly flexible deeply-corrugated tubular metal walls whereby the uniformity and reliability of action and elastic performance of the wall may be improved; or the creep of the wall may be reduced; or the stiffness or modulus of elasticity of the wall may be increased; or the elastic range of movement of the wall may be raised; or the capacity of the wall to withstand a given range of stress may be augmented; or the ratio of deformation to load for the wall may be diminished; or whereby various combinations of these desired characteristics may be secured.

In conformity with the present invention a highly-flexible deeply-corrugated tubular metal wall of any suitable size and metal thickness is made in any suitable way from any suitable metal, such as brass, bronze, copper, teel, cupro-nickel, various other alloys, etc. Preferably the wall is made by a process employing cold working operations so as to obtain the toughness and temper imparted to the metal, particularly the bends thereof, by this mode of fabrication, although other suitable methods of procedure may be followed if desired. Suitable processes for making a wall of this character are disclosed, for example, in the patents to Fulton No. 971,838, granted October 4, 1910, Fulton et al, No. 1,522,051, granted January 6, 1925, and Bezzenberger, No. 1,506 966, granted September 2, 1924.

Following the forming operations, i. e. after the relatively-deep and narrow corrugations have been formed in thin walled tube, the wall is subjected for a relatively short time to a heat treatment at a moderate temperature which is materially below a true annealing temperature, i. e. below that temperature at which the grains become apparently equiaxed. The wall is then preferably allowed to cool gradually, i. e. without quenching.

The temperature to which the metal is subjected in the aforesaid heat treatment may vary within considerable limits; the practical range apparently being between 450° F. and 650° F. or possibly 750° F. The length of time to which the metal should be subjected to the chosen temperature varies inversely with the temperature, decreasing with the increase in temperature and vice versa. As the time limit is a material factor in the efficiency of manufacturing operations, it is desirable to select a temperature which is sufficiently high so that the length of time during which the metal is to be subjected to the heat treatment may be reasonably short. In view of the practical difficulties of maintaining exactly uniform temperatures over considerable periods of time, and of performing manufacturing operations within exact periods of time, it is also desirable to select a time and temperature such that small variations in either of these variables has little or no effect upon the results obtained.

I have discovered from extensive investigations that if the effect of treatments for appropriate lengths of time at different temperatures within the given range be plotted, the graphs take the form of curves with peaks or maxima having different degrees of flatness. Where the peak of the graph is relatively flat, there may be a considerable variation in the time or the temperature, or

both, without substantially affecting the improvement imparted to the wall by the treatment, and I therefore prefer to select such a temperature and time as will permit of substantial variations in time and temperature without materially affecting the resultant qualities.

For purposes of exemplification, a procedure that has been found highly effective in practice will be set forth in detail. A highly-flexible deeply-corrugated tubular wall of 80–20 brass of .008″–.010″ thickness is made in any suitable way, as heretofore pointed out, and is then placed in an oven or kiln and subjected to a temperature of 525° F. for five hours, the interval being measured from that time at which the temperature of the tubular wall reaches 525° F., after which it is allowed to cool without quenching. In this operation the temperature is preferably maintained at approximately the specified figure during the entire period of heating, but the improvement resulting from this treatment at this temperature and time is such that a variation in temperature of three or four per cent either above or below the selected degree does not substantially affect the result; nor are the resulting characteristics of the wall substantially altered if the walls are left in the oven somewhat longer than the five hours or removed somewhat prematurely. Hence this procedure is particularly suitable for manufacturing operations where unskilled labor is conventionally employed, because inattention of the employees within moderate limits does not materially impair the results of the treatment.

It is to be expressly understood, however, that this particular time and temperature have been selected only as exemplary. A lower temperature may be used down to approximately 450° F., but to secure the full benefits of the treatment at this temperature, the time of heating must be increased more than 100%, and the time element enters as an undesirable factor. On the other hand, the time element may be decreased by using a higher temperature up to 650° F., (and possibly with very close regulation up to 750° F.)—the time interval for 600° F. being approximately thirty minutes—but with this increase in temperature greater care must be exercised in maintaining the predetermined temperature and closely regulating the time of heating, because it has been found that over-treatment at the higher temperatures is productive of a material impairment of the desired qualities, and the closeness of control required near the upper limit of the range may be such as to render the treatment undesirable as a manufacturing procedure.

The time-temperature relation for effecting the greatest improvement in elastic performance appears to be somewhat lower than the time-temperature relation required for producing the optimum effect in increasing the capacity of the wall to withstand repeated flexure through a given range of stress, and therefore the time and temperature must be selected with regard to whether the elastic range of action or the endurance life or capacity to withstand repeated stress is to be most improved. The exemplary procedure outlined above has been selected with regard to the greatest increase in elastic performance; but this temperature and time of treatment are also suitable for substantially increasing the capacity of the wall to withstand repeated stress without injury.

Experience has also demonstrated that the treatment that is exemplified above substantially reduces the tendency of the wall to creep, or increase its free overall length, when subjected under stress to the action of steam or other heated fluids, and will in fact decrease the creep to such an extent that it becomes of little, or no, consequence. The exemplary procedure above outlined is also productive of a substantial stiffening of the metal, i. e. the extent of deformation of the resulting wall under a given load, or the ratio of deformation to load, is decreased.

The maxima of the time-temperature curves which represent the greatest decrease in the creep, or which correspond to the greatest stiffening effect, are not necessarily coincident with the peak of the corresponding curve for the greatest improvement in elastic performance; for example, a treatment of 500° F. from two to four hours produces a greater elimination of the tendency to creep, and for this reason the time and temperature elements must be selected in conformity with the desired characteristics of the resulting wall. But experience has demonstrated that the exemplary procedure outlined above concurrently reduces the tendency of the wall to creep and at the same time produces a substantial stiffening effect, and also increases the elastic range of action and the endurance life. Change in the metal used may somewhat change the time and temperature for the optimum improvement in any given characteristic, although investigations carried out with a number of different alloys show that the curves for different metals follow closely those obtained for 80–20 brass.

Given the characteristics desired in the final wall, the curves of improvement in those characteristics for different times and temperatures—decreasing the time as the temperature increases and vice versa—can be readily plotted; and taking into consideration the flexibility of time and temperature relation that is permissible, and using the preceding disclosure as a guide, those skilled in this art may readily determine the heat

treatment which is most suitable for imparting the desired characteristics to such walls under conditions which are advantageous and economical in the manufacture of said walls for various purposes.

What is claimed is:

1. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, forming relatively-deep and narrow corrugations in a thin-walled tube, and heat treating said deeply-corrugated wall at a temperature of from 450° F. to 750° F. for a predetermined time.

2. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, forming relatively-deep and narrow corrugations in a thin-walled tube, and increasing the elastic range of action of the wall by subjecting it for a predetermined time to a temperature materially less than that required to effect equiaxing of the grains.

3. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, forming relatively-deep and narrow corrugations in a thin-walled tube, and increasing the capacity of the metal to withstand repeated stress by heat treating the deeply-corrugated wall for a predetermined time at a temperature maerially less than that required to effect equiaxing of the grains.

4. In the manufacturing of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, forming relatively-deep and narrow corrugations in a thin-walled tube, and decreasing the creep of the wall by heat treating the deeply-corrugated wall for a predetermined time at a temperature materially less than that required to effect equiaxing of the grains.

5. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, forming relatively-deep and narrow corrugations in a thin-walled tube and decreasing the ratio of deformation to load by heat treating the deeply-corrugated wall for a predetermined time at a temperature materially less than that required to effect equiaxing of the grains.

6. The method of improving action of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, which includes heat treating the deeply-corrugated walls at a temperature of 450° F. to 650° F. for a pretermined time.

7. The method of making highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, which includes forming relatively-deep and narrow corrugations in a thin-walled tube by cold working operations which impart, toughness and temper to the metal, and then heat treating said wall at a temperature of 450° F. to 650° F. for a predetermined time.

8. The method of making highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, which includes forming relatively-deep and narrow corrugations in a thin-walled tube by cold working operations which impart toughness and temper to the metal, and then heat treating said wall at a temperature of 500° F. to 600° F. for a predetermined time.

9. The method of making highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, which includes forming relatively-deep and narrow corrugations in a thin-walled tube by cold working operations which impart toughness and temper to the metal, and heat treating said wall at a temperature on the order of 525° F. for a period of time on the order of five hours.

10. In the manufacture of highly-flexible deeply-corrugated tubular metallic walls of copper, copper alloys and the like possessed of resiliency and adapted to be subjected to repeated stress, changing one or more of the characteristics of said wall by subjecting the metal after the forming operation to a temperature on the order of 500° F. to 600° F. for a predetermined period of time.

11. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, the step which includes heat treating the metal after the forming operations at a temperature on the order of 525° F. for a predetermined period of time.

12. In the manufacture of highly-flexible deeply-corrugated tubular metal walls of copper, alloys of copper and the like, the step which includes heat treating the metal after the forming operations at a temperature on the order of 525° F. for a period of time on the order of five hours.

13. In the manufacture of highly-flexible deeply-corrugated tubular metallic walls of copper, alloys of copper and the like and possessed of resiliency, the method of decreasing the creeping of the walls under load at operating temperatures comprising subjecting the walls to a temperature of 600° F. to 500° F. for from one to five hours.

14. A heat treatment for a flexible deeply-corrugated wall composed of a metallic alloy, comprising maintaining the wall at a temperature of from 600° F. to 500° F. for from one to five hours, the duration of the treatment being proportioned substantially inversely to the temperature selected, within said limits.

In testimony whereof I have signed this specification.

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