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[54] PRODUCTION OF METAL TUBING WITH ROUGH INNER SURFACES

6 Claims, No Drawings

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[50] **Field of Search** 148/11.5, 12; 72/286, 367, 370

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ABSTRACT: Metal tubing having inner surfaces of a controlled roughness of a sand-grained type consistency are characterized by (1) the same or only a slightly higher resistance to flow, (2) a higher heat-transfer coefficient and (3) a higher energy ratio (which is defined as the ratio of thermal energy transmitted to mechanical energy expended) when compared to smooth tubing having the same internal diameter. To produce metal tubing having this controlled roughness, the tubing is overannealed to produce excessive grain growth of the metal and is then radially inwardly deformed to force the grains adjacent the inner surface into alignment in a generally inwardly direction thereby resulting in the desired roughening of the inner surfaces of the tubing. The degree of roughness is determined by the extent of overannealing and inward deformation.

PRODUCTION OF METAL TUBING WITH ROUGH INNER SURFACES

INTRODUCTION

This invention relates to metal tubing having inner surfaces of a controlled roughness of a sand-grained type consistency and to a method for the manufacture of such metal tubing. More particularly, the invention relates to a method of manufacturing metal tubing with a controlled inner surface roughness having improved heat transfer characteristics and the same or only a slightly higher friction factor as smooth tubing of the same internal diameter. The method of the invention is particularly applicable to the production of metallic tubing for use in heat exchange equipment and boilers.

Seamless metal tubing is usually manufactured by the conventional plug and die method, in which the tubing is drawn through a confining opening to reduce its outside diameter and the wall thickness of the tubing is reduced simultaneously by placing a plug inside the tubing in the same transverse plane as the die. The cross section of the finished tubing thus approximates the annular space between the plug and the die.

Although the advantages of increased heat-transfer efficiency for tubing with roughened internal surfaces has been recognized, all existing techniques for roughening the internal surface of metal tubing yield a somewhat random degree of roughness for the inner surface, which in turn, results in erratic heat-transfer coefficients for such tubing. At present the only practical method for roughening the internal surface of metal tubing requires the use of sandblasting the interior of the tubing after the tubing has been subjected to the conventional plug and die method of manufacture. Sandblasting the interior surface of tubing is not only costly but cannot be done with consistently close control of the degree of roughness.

STATEMENT OF THE INVENTION

During an extensive investigation into the properties of metal tubing with rough internal diameters, it has been found that when metal tubing is deliberately overannealed for a period of time sufficient to produce grain growth greatly in excess of that produced by the normal annealing of tubing of that metal, and when the tubing wall of such overannealed tubing is radially inwardly deformed at ambient temperature so that there is free movement of the grains adjacent the inner surface of the tubing, it is possible to consistently produce tubing having the desired degree of roughness in its inner surface. Metal tubing with a rough internal diameter (or "RID tubing", the two terms being used interchangeably) produced by this method is characterized by (1) the same or only a slightly higher resistance to flow, (2) a higher heat-transfer coefficient and (3) a higher energy ratio (which is defined as the ratio of thermal energy transmitted to mechanical energy expended) than smooth tubing of the same metal having the same internal diameter.

Based on these discoveries, the invention provides an improved method for manufacturing metal tubing having an inner surface with a controlled degree of roughness which comprises

a. heating the tubing to its annealing temperature for a period of time sufficient to produce gain growth greatly in excess of that formed by the normal annealing of such metal tubing, and

b. radially inwardly deforming the tubing wall of the overannealed tubing at ambient temperature while permitting free movement of the grains adjacent the innner surface of the tubing, the amount of such deformation being sufficient to radially inwardly dislocate the grains adjacent the inner surface of the tubing enough to produce a predetermined degree of inner surface roughness.

DISCUSSION OF PROCESS

The method of the invention for manufacturing metal tubing having an inner surface of controlled roughness is applicable to the production of tubing of any metal or metal alloy, particularly to those metals which are used in conventional drawing operations. These include the softer metals and their alloys, especially copper, brass and aluminum.

To manufacture RID tubing in accordance with the invention, the metal tubing must be overannealed. Put another way, the annealing of the tubing is sustained at a temperature and for a time sufficient to cause the grains of the metal to grow to a size much larger than those encountered in normal mill practice. Depending on the metal used, the desired grain size after annealing should be at least 1.5 times the size to which such grains are normally annealed, but may be 4 or 5 times as great. In the case of copper, the preferred grain size to which copper should be annealed is 0.150 mm. or about 3 times normal grain size. This is an extraordinarily high grain size for copper, since the industry standard for "Dead Soft Anneal" requires an average grain size higher than 0.080 mm.

The precise kind of furnace used for annealing is not essential to the method of the invention. However, good results are obtained for copper by use of a continuous atmosphere furnace heated electrically or by oil or gas. The particular atmosphere introduced into the furnace is not critical so long as the amount of oxidation is not so great as to require so much pickling or other scale-removing operations that the inner surface roughness produced by this technique is impaired. Preferably, neither an oxidizing nor a reducing atmosphere should be employed but one which is relatively inert to the metal. An exothermic atmosphere is suitable for overannealing copper and copper alloy tubing.

To obtain the degree of grain growth required by the present invention, high annealing temperatures and longer annealing times are necessary. For brass, this generally means temperatures above 1300° F. for periods of 10 minutes or more.

Usually the tubing must be annealed for a substantially longer time than is encountered in conventional mill practice. The amount of time necessary to produce the desired grain growth will vary considerably, depending on the annealing temperature. Overannealing can be accomplished by using a combination of furnace temperatures and belt speeds sufficient to cause excessive grain growth but may be conducted either as a batch-type or a continuous process.

The tubing wall must then be greatly compressed, radially, in order to induce the natural, unimpeded dislocation of these overgrown metal grains. Under radial deformation, the grains are made to "pop out" from the plane of the inner surface of the tubing, which, in turn, results in a unique type of inner surface roughness resembling a sand-grain finish.

The radial compression of the tubing wall may be accomplished by drawing or swagging or some other suitable method. Drawing, however, is preferred, but it must be performed in a quite unconventional manner. The overannealed tubing is sunk to finish size by drawing it through a die leaving out the plug on the inside surface. The consequent diameter drop is so great that a die size considerably larger than the desired size of the finished tubing must be used.

This combination of an extremely high grain size in the tubing before sinking and the drastic sinking reduction yields a sand-grained-type roughness on the inside surface of the finished tubing. The degree of roughness is easily controlled by varying the amount by which the tubing is overannealed and the severity of the subsequent deformation.

The unique sand-grained-type roughness thus produced possesses excellent heat-transfer characteristics such as make it ideal for use in heat exchangers, boilers, chillers, and similar apparatus. The present tubing is also inexpensive to manufacture. Indeed, it has been fashioned at less cost than has been regular tubing.

Table I compares the mill practices used in obtaining RID surface copper tubing three-eighths inches O.D.×0.028 inches wall thickness in accordance with the invention with those used in producing the conventional three-eighths inches O.D.×0.028 inches wall thickness copper tubing:

TABLE I

Comparison of Mill Practices for Rid Copper Tubing and Conventional Copper Tubing

RID Tube	Normal Practice
Draw ready-to-finish 5/8"× 0.024/0.026" Wall	Draw 5/8"×0.033/0.034" Wall
Anneal to 0.150 mm. average grain size	Draw 1/2"×0.029/0.031" Wall
Sink to 0.373" O.D. × 0.028/ 0.029" Wall (Use 0.389" Die)	Draw 3/8"×0.028" Wall

CHARACTERISTICS OF RID COPPER TUBING

The uniqueness of RID copper tubing made in accordance with the method of the invention may be understood more easily by separately discussing four important characteristics of this tubing, namely (a) mechanical roughness, (b) resistance to flow, which is known as the friction factor, (c) heat-transfer coefficient, and (d) energy ratio, which is defined as the ratio of thermal energy transmitted to mechanical energy expended.

Mechanical Roughness

Mechanical roughness measurements of RID tubing may be made with a Talysurf instrument, which provides a profile of the inside tube surface which, in turn, gives a rather complete description of the surface. Using RID copper tubing produced in accordance with the method of the invention and having tube dimensions of five-eighths in. O.D. and 0.028 in. wall thickness, the respective root-mean-square value of the roughness was found to be 0.000594 in. and the maximum peak-to-valley measurement was found to be 0.002 in. This RID tubing was also used in the subsequent tests described below.

Friction Factor.

Isothermal friction factor data for the RID tube were obtained over a pipe Reynolds number range of 300 to 20,000. The transition from fully laminar flow to turbulent flow occurred at about a Reynolds number of 2,300. Using the formulas derived by L. F. Moody, Trans. ASME, 66, 671 (1944), it can be ascertained that the (e_s/D) value for this RID tube is no larger than 0.001. This value is not the ratio of the actual physical roughness height to pipe diameter of the tested tube but that of the frictionally equivalent sandgrain tube. The RID tube showed the same friction factor as did the smooth tube in the completely laminar region and conforming to the behavior of sandgrain tubing in the transition region between laminar and fully turbulent flow. This is particularly significant since most commercial rough pipes do not normally behave in this manner, but tend to be very erratic in the transition region. The RID tube showed a slightly higher friction factor in the turbulent zone than did the smooth, up to a Reynolds number of 20,000, the maximum tested.

Heat-Transfer Coefficient

Ordinarily, the heat-transfer data for flow inside tubes in the turbulent region is correlated by the following equation:

$$N_u = C_1 Rey^n Pr^m \quad (1)$$

from which the McAdams equation for fully turbulent flow in smooth tubes is derived

$$N_u = 0.023\, Rey^{0.8} Pr^{0.4} \quad (2)$$

In general, data for RID copper tube are somewhat higher than the smooth tube values. No gain relative to the smooth tube was seen in the heat-transfer coefficient at around 6,000 but as large a gain as 42 percent was observed at a Reynolds number of 40,000. However, a comparison on the basis of performance at equal Reynolds numbers does not provide an adequate method for evaluating the RID tube performance compared to that of smooth tube of the same tube dimensions.

Energy Ratio

To determine the relative heat-transfer improvement of the RID tube over the smooth tube, it is not sufficient to simply compare the heat-transfer coefficients of the RID and smooth tubes at various Reynolds numbers. This is due to the fact that greater pumping power would be needed to attain the same Reynolds number in the RID tube. More important is information showing the respective heat-transfer coefficients of the RID and smooth tubes at the same levels of mechanical power expenditure or pumping power, which information reflects how much thermal energy can be transmitted per unit pumping power, and is a type of tube efficiency. The thermal energy transmission capability is related to the heat-transfer coefficient, and the pumping power expenditure is a function of the Reynolds number cubed times the friction factor. Therefore, what is desired is the ratio of the RID to smooth tube heat-transfer coefficient at various levels of constant pumping power (indicated by the smooth tube Reynolds number).

When this energy ratio was determined for the RID tube, it was found that there was no gain at the lower Reynolds number of 6,000, but the gain was significant at the Reynolds number level of 20,000. An improvement of 25 percent was obtained at the high end of the flows tested. In all probability, the flow range is the most favorable region for this particular RID tubing, since the friction factor for the RID tube did not appreciably differ from that of the smooth tube in this range which undoubtedly will not be true at the higher flow rates.

Considering all of the experimental evidence presently available, RID tubing made in accordance with the invention are characterized by (1) the same or only a slightly higher resistance to flow, (2) a higher heat-transfer coefficient, and (3) a higher energy ratio than smooth tubing of the same metal having the same tube dimensions.

I claim:

1. A method of manufacturing metal tubing having an inner surface of controlled roughness which comprises
   a. heating the tubing to its annealing temperature for a period of time sufficient to produce grain growth greatly in excess of that produced by the normal annealing of such metal tubing, and
   b. radially inwardly deforming the tubing wall of the overannealed tubing at ambient temperature while permitting free movement of the grains adjacent the inner surface of the tubing, the amount of such deformation being sufficient to radially inwardly dislocate the grains adjacent the inner surface of the tubing enough to produce a predetermined degree of inner surface roughness.

2. A method of manufacturing metal tubing having an inner surface of controlled roughness according to claim 1, in which the radially inward deformation of the tubing wall of the overannealed tubing is accomplished by cold drawing the tubing through a die of smaller diameter than the outer diameter of the tubing while permitting free movement of the grains adjacent the inner surface of the tubing, the difference between the die opening and the outside diameter of the tubing being sufficient to radially inwardly dislocate the grains adjacent the inner surface of the tubing enough to produce a predetermined degree of inner surface roughness.

3. A method of manufacturing metal tubing having an inner surface of controlled roughness according to claim 1, in which the radially inward deformation of the tubing wall of the overannealed tubing is accomplished by cold drawing the tubing to finish size through a die larger than finish size but substantially smaller than the tubing diameter without a plug on the inside surface of the tubing.

4. A method of manufacturing copper tubing having an inner surface of controlled roughness according to claim 1, in which the copper tubing is annealed for a period of time sufficient to produce an average grain size of at least 0.150 mm.

5. A method of manufacturing metal tubing having an inner surface of controlled sand-grain-type roughness according to claim 1, in which the sand-grain-type roughness is controlled by varying (i) the grain size achieved by annealing and (ii) the amount of radially inward deformation of the tubing.

6. A method of manufacturing metal tubing having an inner surface of controlled roughness according to claim **1**, in which the tubing is heated to an annealing temperature for a period of time sufficient to produce grains three times the length of those produced by the normal annealing of tubing of that metal.

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