Effects of Rib Dimension Reduction and Orientation Change of Inner Spiral Ribbed Copper Tube Using Tube Sinking Method

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Abstract

This paper deals with the development of ultra-small inner spiral ribbed copper tubes with high quality heat transfer. Due to increased sophistication of modern electronic equipment and electrical appliances, the production technology of inner spiral ribbed fine tubes must allow for the manufacturing of the ultra-small tubes of small size, high quality, high functionality, and at low processing cost. The conventional production method, however, is suitable for production of large tubes with high drawability but not suitable for long ultra-small tubes because with the conventional technology it is difficult to manufacture an ultra-small spiral ribbed mandrel and a floating plug. The aim of this research paper is to identify the optimal reduction area per pass using tube sinking method in light of the effects of rib dimension reduction and orientation change of the inner spiral ribbed copper tube. Twenty-one seamless inner spiral ribbed copper tubes are used as specimens. The specifications of the copper tubes are of 5.00 mm outer diameter, 3.71 mm inner diameter, 0.364 mm wall thickness, 0.28 mm rib height, 0.33 mm rib base width, 0.175 mm rib tip width, 38^{O} spiral angle, 0.393 mm rib pitch, and 45 ribs. In the experiment, the reduction area per pass (Re/P) is increased for each successive tube specimen; that is, Re/P is 2.52% for the first tube specimen, 5.18% for the second tube specimen, and so on until Re/P is 86.63% for the twenty-first tube. Then, all twenty-one tubes are analyzed with respect to nine parameters: reduction per pass ratio, drawing force, drawing stress ratio, wall thickness ratio, rib height ratio, rib base width ratio, rib tip width ratio, rib pitch ratio, and rib spiral angle ratio. The results have indicated that the optimal reduction area per pass in the case of ultra-small inner spiral ribbed copper tubes is 49.76%.

Keywords*:* Inner Spiral Ribbed Tube, Heat Transfer Tube, Small Size Tube, Tube Sinking Method

1. Introduction

The first method of manufacturing inner spiral ribbed tubes was invented over two decades ago and adopted by industrialists for the inner spiral ribbed tube manufacturing. The method has however lost its popularity following the advent of newer, better manufacturing methods, even though it is still sometimes found used in production of large ribbed tubes. The wall of a tube produced with the original method was cylindrical and the internal surface was spirally ribbed with the angle at the central axis at least 35^{O}. The roll forming process in the conventional method to produce a tube with inner spiral ribbed surface started with feeding a flat metal sheet into a series of calendaring machines to be pressed.

The upper roller of each pair of the calendering machine has spiral grooved teeth while the lower roller a smooth surface. The "calendered" metal sheet was then rolled up along its length and both edges were welded together lengthwise, the product of which was an inner spiral ribbed tube [1].

Significant improvement to the manufacturing method of inner spiral ribbed tubes was made in 2007 with the introduction of a ribbed mandrel and a floating plug connected to a tie rod [2, 3]. In drawing a steel ribbed tube, top surface of a spiral ribbed mandrel serving as the drawing plug always remains in contact with the surface of a blank tube from the initial contact to rib formation, by which the blank tube is processed to product size. This production method makes possible long tube processing and has several advantages, such as forming capability and durability of the finished steel tube [4, 5].

Presently, copper tubes with inner spiral ribbed surface and seamless, smooth outer surface available in the marketplace are of 5.00 to 15.00 mm in outer diameter. Unlike blank tubes, tubes with inner spiral ribbed surface allow more heat transfer [6, 7]. Besides, the inner spiral ribbed surface improves efficiency of the heat exchanger of condensation or vaporization of refrigerant [8]. Applications of the inner spiral ribbed copper tubes are found in evaporators and condensers of air conditioning units, copper tube freezers, and refrigerators [9, 10].

This research work examines the behavior of various parameters of the inner spiral ribbed copper tube (ISRCT), which was manufactured by the ultra-small tube drawing method. In this paper, seamless 5.00mm-diameter copper tube specimens were drawn using the tube sinking method. The experiment results could be applied to the manufacturing of ultra-small inner spiral ribbed copper tubes. The ultra-small tubes would be of great use to heat transfer in heat exchanger components of electrical gadgets with limited heat transfer area.

2. Theory

Tube drawing operations involve tube extrusion (hot working process) and the tube is then drawn through a die (cold working process). Contact between the tube and the die results in plastic deformation, which causes compressive stress to occur, and the tube from the drawing operations is typically of circular shape even though other shapes are possible but infrequently produced. With each successive drawing, the tube diameter is reduced proportionately to a decrease in the cross-sectional area. As illustrated in Fig. 1, currently there exist four methods of tube drawing, i.e., sinking, fixed plug, floating plug, and moving mandrel [11].

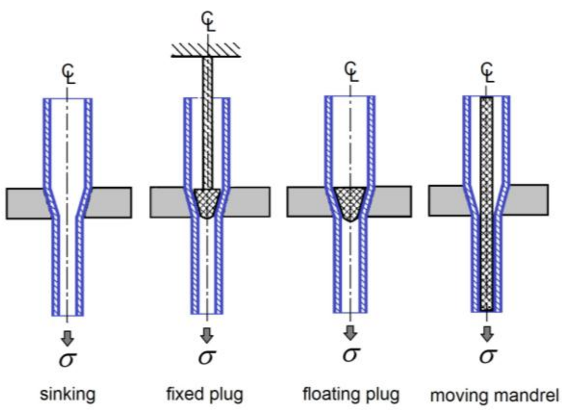

Fig. 1 The existing methods of tube drawing

Of the four methods of tube drawing, it has been found that the fixed plug, floating plug and moving mandrel methods are not appropriate to drawing the inner spiral ribbed copper tubes, whereas the tube sinking method is most suitable for the task. However, the tube sinking method likely causes tube deformation after drawing, after that the effects occurred, the cross-sectional area of the tube will be reduced and the diameter of the tube can be reduced too.

The standard equation of reduction area [%] is as follows: R_A = Reduction area (%); A_0 = Initial Area (mm^2); A_1 = Final Area (mm^2) [11].

$$RA = \frac{A_0 - A_1}{A_0} \times 100 \quad [\%] \tag{1}$$

The stresses involved in tube sinking can be analyzed by the method of Sachs and Baldwin on the assumption that the wall thickness of tube remains constant. The equation of the drawing stress at the die exit is analogous to that describing the drawing stress in wiredrawing. The cross-sectional area of the tube is related to the middle radius r and the wall thickness h by $A \approx 2\pi r h$ [11].

$$\sigma_{xa} = \sigma_o'' \frac{1+B}{B}\left[1-\left(\frac{A_f}{A_b}\right)^B\right] \tag{2}$$

The yield stress σ_o'' is taken equal to 1.1 σ_o for the complex stresses in tube sinking. A more complete analysis of tube sinking has been given by Swift [11].

3. Specimen and Experimental Method

Twenty-one seamless inner spiral ribbed copper tubes were used as specimens. The specifications of the copper tubes are of 5.00 mm outer diameter, 3.71 mm inner diameter, 0.364 mm wall thickness, 0.28 mm rib height, 0.33 mm rib base width, 0.175 mm rib tip width, 38^{O} spiral angle, 0.393 mm rib pitch, and 45 ribs (mother tube). A mother tube was prepared in the setup with its outside surface cleaned and coated with a Teflon resin lubricant, and then drawn the tube by using sodium steerage lubricant. The tungsten die was employed in this experiment. The die half-angle was 12 degrees $(\alpha = 12^O)$ and the drawing speed remained constant at 150 mm/s. In the experiment, the reduction area per pass (Re/P) was increased for each successive tube specimen; that is, Re/P is 2.52% for the first tube specimen, 5.18% for the second tube specimen, and so on until Re/P is 86.63% for the twenty-first tube. The sinking method was selected as the drawing method for the entire experiment.

Table. 1 Material properties and the conditions on drawing which is used in the experiment

Parameters	Copper
Young's modulus, *E* (GPa)	110
Yield stress, σ_y (MPa)	79
Ultimate stress, σ_u (MPa)	180
Poisson's ratio, ν	0.33
Die half-angle, α (deg)	12
Coefficient of friction, *μ*	0.02

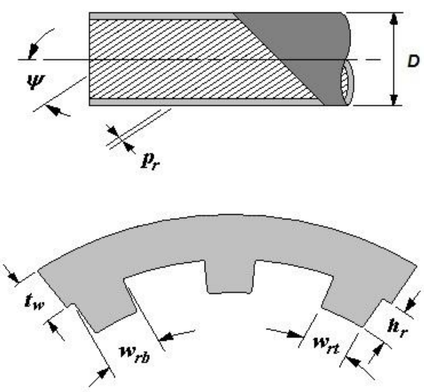

Fig. 2 The cross-sectional and longitudinal depictions of the inner spiral ribbed copper tube: *D* = Outside diameter; ψ = Ribbed spiral angle (deg); P_r = Ribbed pitch (mm); t_w = Wall thickness (mm); h_r = Ribbed height (mm); w_{rb} = Ribbed base width (mm); w_{rt} = Ribbed tip width (mm).

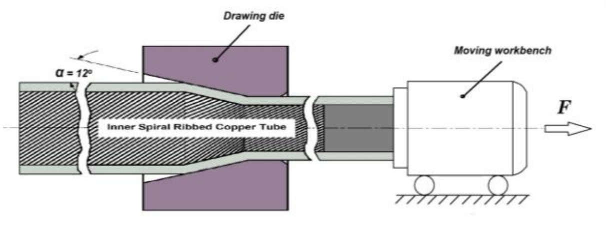

Fig. 3 Experimental model by using the axis force in drawing and use a method of a hollow tube. The die half-angle, the minimum Re/P of the first draw, and the maximum Re/P of the final draw (twenty-first) were 12 degrees, 2.52%, and 86.63%, respectively.

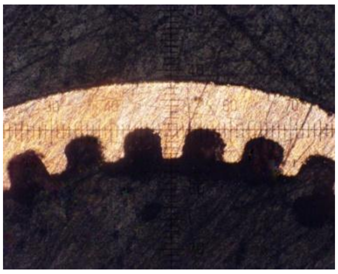

Fig. 4 The cross-section of the rib of mother tube

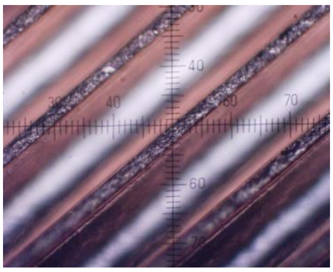

Fig. 5 Rib spiral angle - mother tube

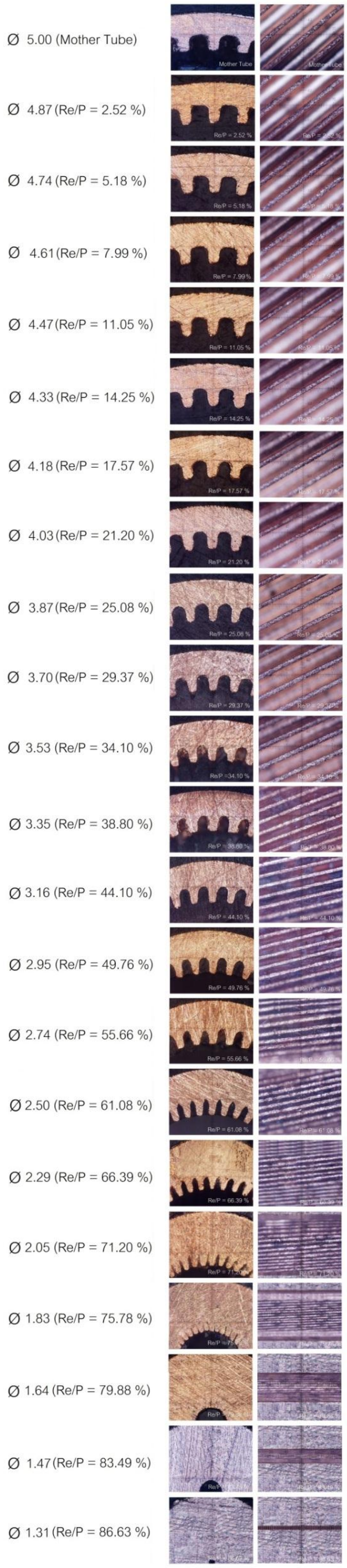

Fig. 6 The cross-sectional and longitudinal profile of the inner spiral ribbed copper tubes using the tube sinking method for the maximum total reduction of 86.63% and $\alpha = 12^o$.

4. Results and Discussion

4.1 Change of the shape

Behavior of copper tubes has a spiral ribbed on the surface inside the tube after drawing. The size of the cross-sectional area of a spiral ribbed on the surface inside the tube was changed after deformation the body by drawing into hollow tubes. The results showed the details of the cross-sectional area of a spiral ribbed on the surface inside the tube which drawing to change from the lowest Re / P = 2.52% to the highest until the Re / P = 86.63%, with an experimental approach. Beyond the reduction area per pass (Re/P) of 49.76%, flute marks were found at the top of the ribbed and lug marks on the back side of the several ribbed. Moreover, it was found that it had the grooves and the fissures around the boundary of several ribbed which occurs at the same time different dimension sizes maybe not the same form their distribution may not be uniform the same form all over the boundary. It's spread out until the width expansion all over the area. They would be compressed into the ribbed and the shape of the ribbed becomes the shape that was deformed as shown in Fig. 6 The size of the cross-sectional dimension and the angle of internal spiral ribbed has changed after the drawing and the results have shown that the thickness of the wall is increased after the drawing but it is not always the same, the height of the ribbed (ribbed height), the width of the base of the ribbed (ribbed base width), the width of the top of the ribbed (ribbed tip width), the distance between the ribbed (ribbed pitch), the angle of the ribbed (ribbed spiral angle) will decrease repeatedly and continuously after the reduction of the cross-sectional area every different time. However, for a single ribbed the expansion of the strain varies from the base of the ribbed to the top of the ribbed. Strain that occurs was in the main part of the ribbed more than the top. So changing the shape at the base of the ribbed more intense than at the top of the ribbed and the changing of the angle of spiral ribbed has changed in the negative way.

4.2 Stress analysis

The tube sinking includes axial stress (tensile stress), radial stress (compressive stress) and hoop stress (circumferential stress in a cylindrically shaped part as a result of internal or external pressure). Axial stress is the tensile stress, which is almost the same as the value in the tube wall area, but grows quickly in the ribbed area. Radial stress is the compressive stress in tube wall zone, but it may change into tensile stress in the ribbed area. Hoop stress is the compressive stress; its absolute value grows in radial in the tube wall region, but reduces dramatically in the ribbed region. Effective strain reaches its maximum value on the blending region inside the spiral ribbed tubes. The relationship between reduction per pass ratio and total reduction is shown in Fig. 7 The reduction per pass ratio and total reduction increases repeatedly and continuously because of the reduction of the cross-sectional that decreased in the same direction after forming of 21 testing tubes (specimen). The outside diameter and the dimension sizes of the ribbed decreased again and again. Similarly, the drawing force that used to form all 21 testing tubes and the sum of the size reduction will increase to over and over again and is going to continue because of the force in drawing was used in one direction along the axis will increase and a decrease in the cross-sectional area that was reduced relate to sum of the percent of size reduction (total reduction). The relationship between drawing force and total reduction is shown in Fig. 8 The drawing stress ratio and total reduction increase repeatedly and continuously because the cross-sectional area decreased. But the drawing force that was used to drawn up the percent increase together with the sum of the reduction, which tends to increase depending on the ratio of the stress in the drawing itself. The ratio of drawing stress (drawing stress ratio) is greater than 1 because it was more repeatedly and continuously throughout the 21 times. The relationship between drawing stress ratio and total reduction is depicted in Fig. 9

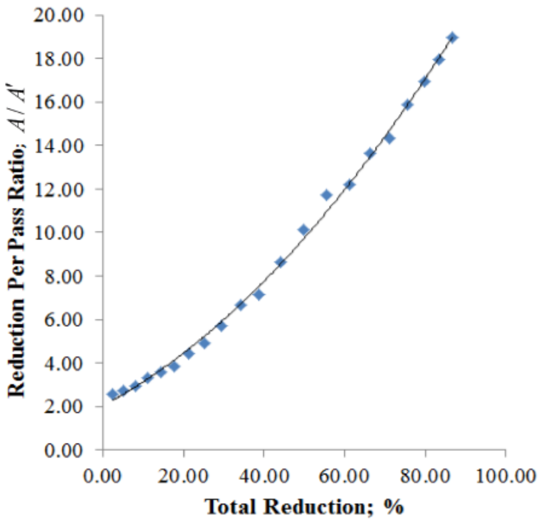

Fig. 7 Changes of reduction per pass ratio

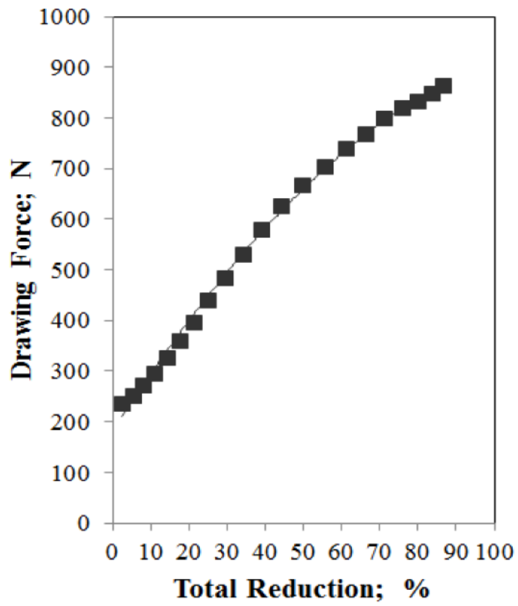

Fig. 8 Changes of drawing force

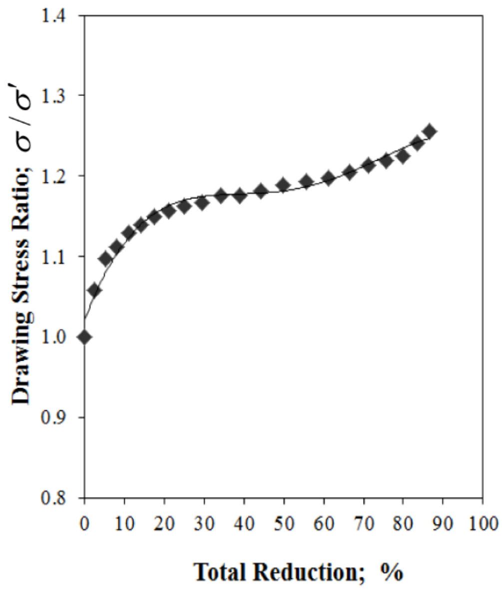

Fig. 9 Changes of drawing stress ratio

4.3 The analysis the reduction of the dimensions of the ribbed

The wall thickness ratio and total reduction are increased from Re/P of 2.52% for the first tube specimen, 5.18% for the second tube specimen, and so on until Re/P is 86.63% for the twenty-first or final tube. This is because, outside diameter was reduced while the tube itself was considered that the compressive stress in one direction along the circumference of the tube. The relationships between wall thickness ratio and total reduction are shown in Fig. 10 The ribbed height ratio and the total reduction repeatedly and continuously in the same period. As the outside diameters are reduced, the compressive stress inside the tubes increases. Thereby, the directions along the circumference of the height of the ribbed were compressed. The relationships between rib height ratio and total reduction are depicted in Fig. 11 The ribbed base width ratio and ribbed tip width ratio were likely to be reduced due to the compressive strain in the circumferential direction of the tube and non-pressure inside the tube over the deformation resistance of the tube. The relation between ribbed base width ratio, ribbed tip width ratio and percentage of total reduction area is shown in Fig.12, 13, respectively.

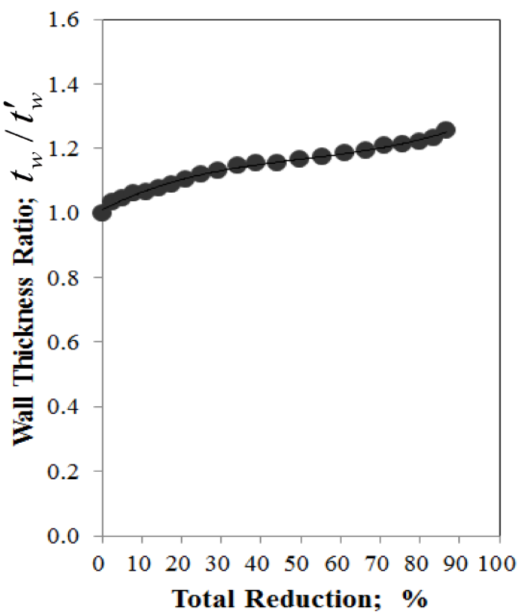

Fig. 10 Changes of wall thickness ratio

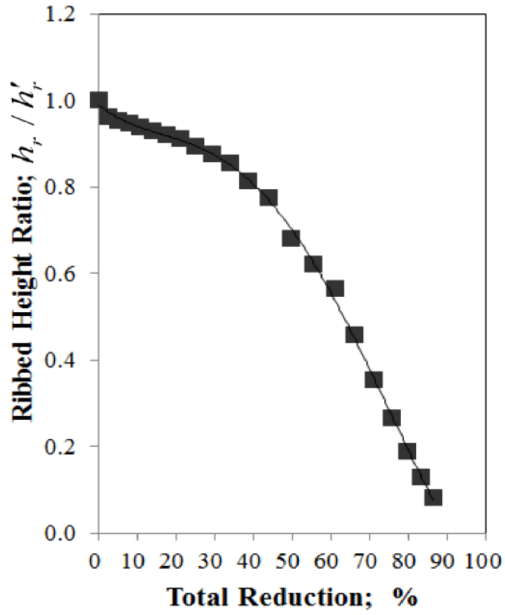

Fig. 11 Changes of rib height ratio

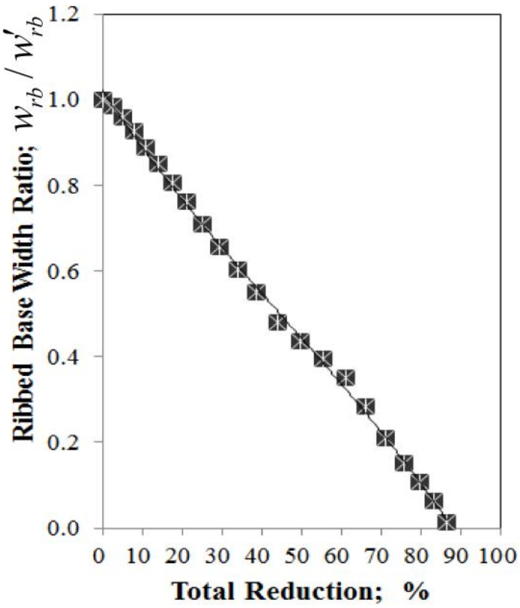

Fig. 12 Changes of rib base width ratio

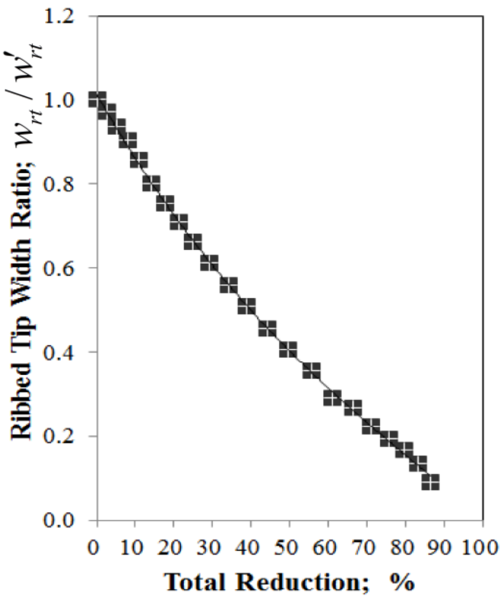

Fig. 13 Changes of rib tip width ratio

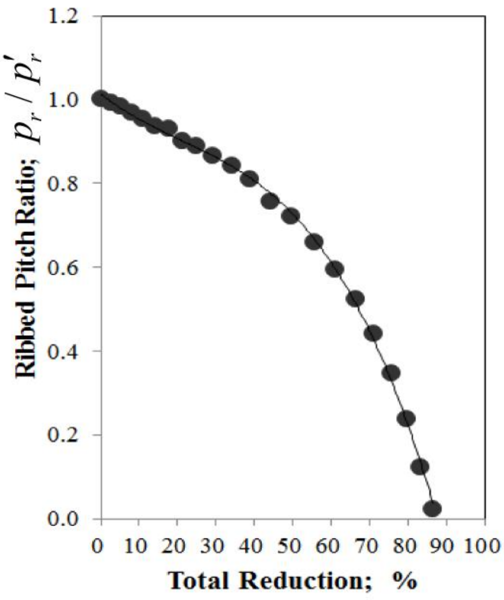

Fig. 14 Changes of rib pitch ratio

4.4 The analysis of the changes which occurred in tubes that was an inner spiral ribbed

The ribbed pitch ratio and the total reduction its size, down repeatedly and continuously because the outside diameter is reduced. While the tube was considered that it got the compressive stress in the circumference of the tube, which is likely to depend on the ribbed pitch ratio. The relationships between rib pitch ratio and total reduction are shown in Fig. 14 The ribbed spiral angle ratio and the total reduction its size down repeatedly and continuously because of a period of elongation in the axial direction, the trend was from the ribbed spiral angle ratio. It will decrease after the Re/P percent of increasing the amount continuously increasing throughout 21 times. The relationships between rib spiral angle ratio and total reduction are illustrated in Fig. 15

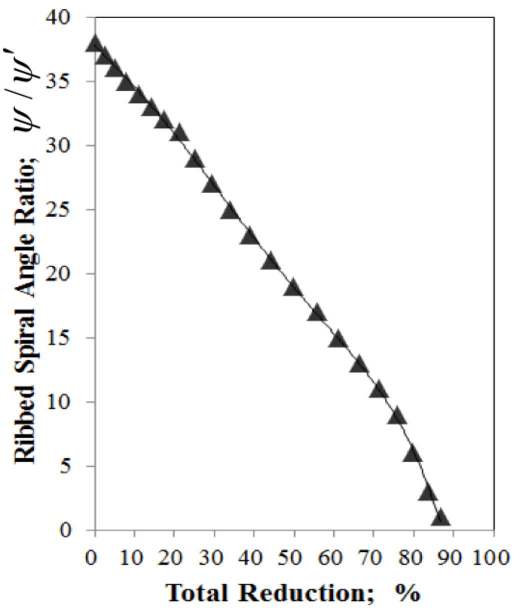

Fig. 15 Changes of rib spiral angle ratio

4. Conclusions

This work has discussed the effects of rib dimension reduction and orientation change of inner spiral ribbed copper tubes using the tube sinking method. The experimental outcomes are described below:

[1] The tube sinking is a process which arising from stress, including the axial stress,

radial stress and hoop stress. The compressive stress will occur at the tube wall. But it may change to the tensile stress within the area of the rib. Compressive stress is the fact value that distributed within the range of the radius of the tube wall and unexpectedly reduced within the area of the rib. It will have the same value of what occurs in the area of the wall and rapidly expanding in the area of the rib.

[2] About the expansion of the effectiveness strain that happened at that time will have the highest value assimilation within the limits of the boundary between the rib and the spiral angle of the rib, in the rib area will delicate and fragile easier than the surface of the tube wall, while using tube sinking drawing method.

[3] During using tube sinking drawing, the inner spiral rib has changed a lot including the thickness of the tube wall, which increased repeatedly and continuously. But the ribbed height, ribbed base width, ribbed tip width, ribbed pitch, and ribbed spiral angle was decreased after that the spiral angle of the ribbed will change a lot.

[4] The tube sinking drawing in the case of a copper tube with a spiral rib inside; the total reduction that was the most appropriate must not exceed 49.76 percent because it will have the grooves and fissures at the side of the ribbed.

5. Acknowledgements

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