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The Use of Rational Design in the Development of an Improved Plug Tool for the Rotary Tube Widening Process

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Abstract

To improve the performance of any metal forming process, a minimization in the process load parameters is needed. The used die geometry significantly affects the process performance. Several die designs were developed to increase efficiency and reduce defects. This paper investigates the effect of the widened plug profile on the tube widening process, and considers the use of the Constancy of the Ratios of successive generalized Homogeneous Strain (CRHS) increments concept for different die profiles. Five widening process parameters are considered: the axial plug load, the widening torque, the variation in temperature, the widened tube thickness, and the widened tube quality. The investigation shows that an improvement in the widening process parameters was achieved using (CRHS) plug design leading to a 25% increase in the maximum widening ratio compared to other plug designs. This was achieved at relatively low tube ends temperature and an improved quality of widened tube ends.

Keywords: : Tool Design; Tube Widening Process; CRHS Concept; Widening Load Parameters; Temperature.

1. Introduction

Many deformation processes have been used as manufacturing processes to widen the tubes ends [1] in order to facilitate the requirements for overlapping joining of tubes and pipes. The sealing condition in the joining portions of the pipes networks may play an important reason in their failure [[2], and calls for improving the quality of the tube end to minimize that problem.

Different deformation process techniques have been adopted to widen the tube ends with certain widening ratio. A plug maybe inserted as a tool to widen the tube end. This has given a limitation in the maximum achievable widening ratio (the ratio of the final internal tube diameter to the initial internal tube diameter). The process is critical as the quality of the widened tube end depends on several process parameters, such as the plug geometry and its axial load and torque [3].

The use of hydrostatic pressure and a press with ball-shaped tool were also considered in different studies for tube widening [4]. However, these techniques required the use of complex tooling and the amount of load and consumed power were high.

Ball shaped and truncated conical plugs have also been used in conjunction with the rotary forming process, in which the formed elements are rotated during forming [5] [6]. It was established that the rotary process gives high quality products with good geometry shapes. This led to an increase in the use of rotary forging and tube spinning in producing flanges and elongated tubes [7] [8].

The main aim of using different widening tools for tube ends in rotary forming processes was to investigate their effect on the process parameters. The ball shaped tool, for instance, has been used to determine the maximum widening ratio, which can be achieved with the increase in ball diameter and tube thickness. Using these techniques, a maximum widening ratio of 2.0 was achieved [5]. The process axial load, specific widening pressure and its defects have also been given. When the ball rests on bore, a force is required to overcome friction and a sharp increase in load is noticed.

It can be concluded from the previous research that the widening tool shape with the tube rotary has a large effect on the process parameters and calls for selecting a rational tool design method to improve them. The concept of the Constancy of the Ratios of successive generalized Homogeneous Strain increments (CRHS) has been adopted in many metal- forming processes, such as: tube elongation [9], tube piercing [10], and the extrusion of tubes and cans [11–12]. It has been concluded that the designed tools using the CRHS concept give high products quality while minimizing the load required in performing the process. This is referred to as the reduction of the redundant shear strain and consequently of the work redundancy.

The ever-increasing demand for high quality product in metal-forming processes necessitated the establishment of working zone improved geometry by suggesting rational methods of tool design. Nevertheless, the majority of these methods can only deal with specific processes. The CRHS concept showed a substantial reduction in the magnitude of in-homogeneous deformation [13]. The incidence of redundancy shearing strains was estimated and the

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correlation between force parameters and the work redundancy of the system was made.

Furthermore, and to show the superiority of the curved dies over the conventional conical dies for a wide range of reductions and frictional conditions, Blazynski *et al*. [11] reviewed many investigations which were based on slip-line field, upper-bound and visioplasticity analytical methods, to show the superiority of the curved dies over the conventional conical dies for a wide range of reductions and frictional conditions.

The CRHS concept is adopted in this study for the plug, due to its successful application in other metal forming processes and because it produces a curved profile with different rates of deformation.

2. Theoretical Background

The axial plug load and the torque are the main two force parameters that must be considered in any seamless tube manufacturing, using a rotary forming process [10]. Therefore and in order to improve the performance of any of these processes, these two parameters must be minimized as much as possible.

As the plug tool is used to widen the tube end in the rotary tube process, the forward movement of that plug inside the tube leads to increasing the axial plug load to overcome the friction, and dislocate the tube material size which is required to achieve the designed widening ratio of the tube end. This is also what is expected for the process torque parameter. From that, the geometry of the widening plug profile plays an important role in the magnitude of the axial plug load and the torque as the variation of the plug profile affects the contact area between the tube and the plug and the total dislocation distant of the tube material size under widening.

The CRHS concept, which has been applied to determine the widening plug profile, relies on the consideration of the homogeneous strain level (ε_H) in (n) equispaced transverse sections of the pass and is defined by the following equation [9]:

$$Z_n / Z_{(n-1)} = (Z_1)^{S(n-1)} \quad (1)$$

Where Z is defined by the physical dimensions of the work piece. Thus $\ln(Z) = \varepsilon_H$. S is the rate of deformation unrelated to time. The value of S determines the mode of deformation, and so, S = 1 corresponds to a uniform rate of flow (UCRHS), S > 1 corresponds to an accelerated rate (ACRHS), and S < 1 corresponds to a decelerated rate (DCRHS). Thus there are three sets of plug profiles that can be designed for each value of tube widening ratio used in this research.

Copper metal has been used as a model material to determine the effect of the widening plug profile on the process parameters. Thus is due to reasons of economy and the limitation of laboratory facilities. It is important to note that the basic requirement demanded of a model material is that its mechanical behaviour should resemble, as closely as possible, the prototype material required to be simulated [14] [15]. This technique has solved many problems in estimating the actual work parameters in metal-forming processes.

3. Experimental Setup

To determine the effect of the widening plug profile on the performance of the process, Copper tubes have been used with different wall thickness of 2, 2.5, 3, and 3.5 mm and with a constant internal diameter of 12 mm. Regarding the widening plugs, different plug diameters of 18, 22, 24, 28, 30 and 32 mm have been used to give different widening ratios; 1.50, 1.83, 2.00, 2.33, 2.50 and 2.67. It has to be noted here that the plug profile shape is governed by the constant (S), which determines the rate of deformation for each diameter.

The designed plug profiles of three different rates of deformation (S); 0.9, 1.0 and 1.1 were based on the CRHS design concept. For practicality, a plug advance (The length of the plug profile, Xp) of 12.5 mm has been used [9] [10]. The respective changes in plug profiles and their dimensions are shown in Figure 1 and Figure 2. Plugs specifications are given in Table 1.

To run the experimental part of the research, an automated drill machine with a dynamometer device (Model No. BKM2000 – TeLC Co.) was used. Technical modifications were made in order to facilitate the measurement of the axial load and torque during the widening process of the tube ends with different plug profiles. At the same time, a temperature measurement sensor (TeLC Co.) was used to measure the temperature increase during the operation of widening the tubes end. The process was carried out at a feed rate of 0.1 mm/rev. and a spindle speed of 475 rpm. Oil was used as a lubricant. The experimental process set up is shown in Figure 3.

4. Experimental Results and Analysis

To show the effect of the widening plug profile type on the process performance, several experiments were carried out for the different plug dimensions shown in Table 1 and the process parameters were measured to check the widened portion of the tube and the quality of deformation. The results will be considered in the next five sections.

4.1. Axial Plug Load

The values of this process parameter were obtained using the load measurement Dynamometer. Figure 4 shows a plot of these results for different widening ratios, tube thicknesses and plug profiles. It can be seen that the axial plug load increases with the increase in the widening ratio. This is due to the increase in the contact area between the widening plug profile and the tube material. Table 1 has shown that the surface area of the plug profile is higher as the widening ratio and plug diameter increase. Again, the axial plug load increases with the increase of the tube thickness, since the displacement of the material volume increases in unit time.

Figure 4 also shows that the ACRHS plugs give the lowest values of axial plug load, while the DCRHS plugs profile result in the highest. The reason of that can be explained with reference to Figure 5, which shows the mechanism of the tube metal flow during the widening process using different plug profiles. It can be easily noticed that the lowest metal flow displacement in the deformation zone occurs using the ACRHS plug profile.

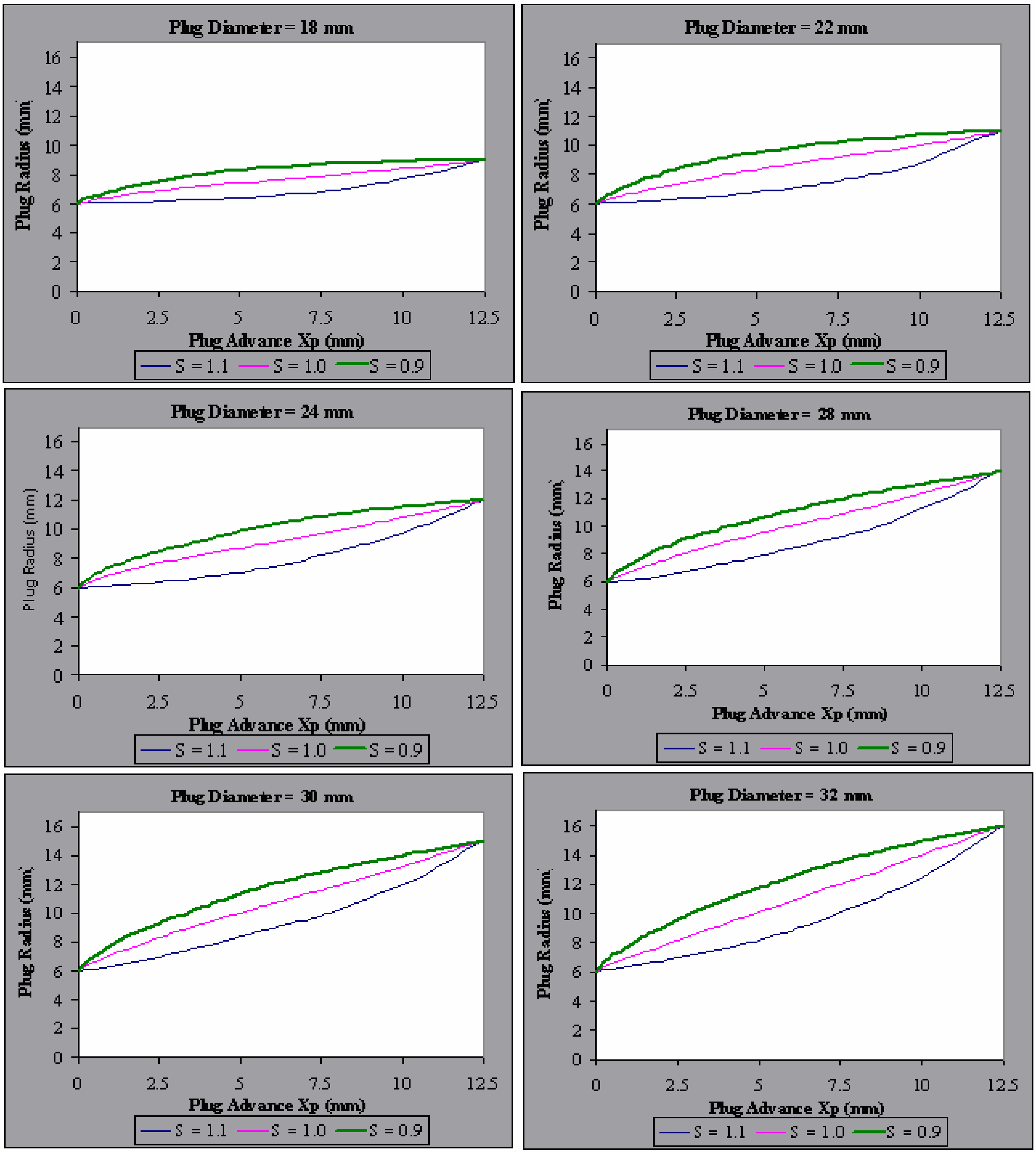

Figure 1. CRHS – Concept design of widening plug profile (S is the rate of deformation).

Opposite to that, the metal flow displacement is highest with the DCRHS plug profile.

The experiments have shown that using the ACRHS plug profile and for the widening ratios of 2.50 and 2.67, the shape of the widened tube end has become a round flattened flange. This is due to the magnitude of the inclination angle of the ACRHS plug profile, as it is increased, at the rear portion, with the increase of the plug diameter. As a result, this pushes the tube metal out of the cylindrical part of the widening plug, as illustrated in Figure 6.

4.2. Widening Torque

The variation of the widening process torque with the different widening ratios, tube thicknesses and plug profiles is given in Figure 7. As seen, the general behaviour of the widening torque increases with the increase of the widening ratio, which is similar to the increases in the axial plug load. This is due to the increase in both of the contact area between the widening plug profile and the tube material, as the plug diameter increases, and to the increase of the plug profile length, as shown in Table 1. Also, the widening torque increases with the increasing of the tube thickness and this is due to

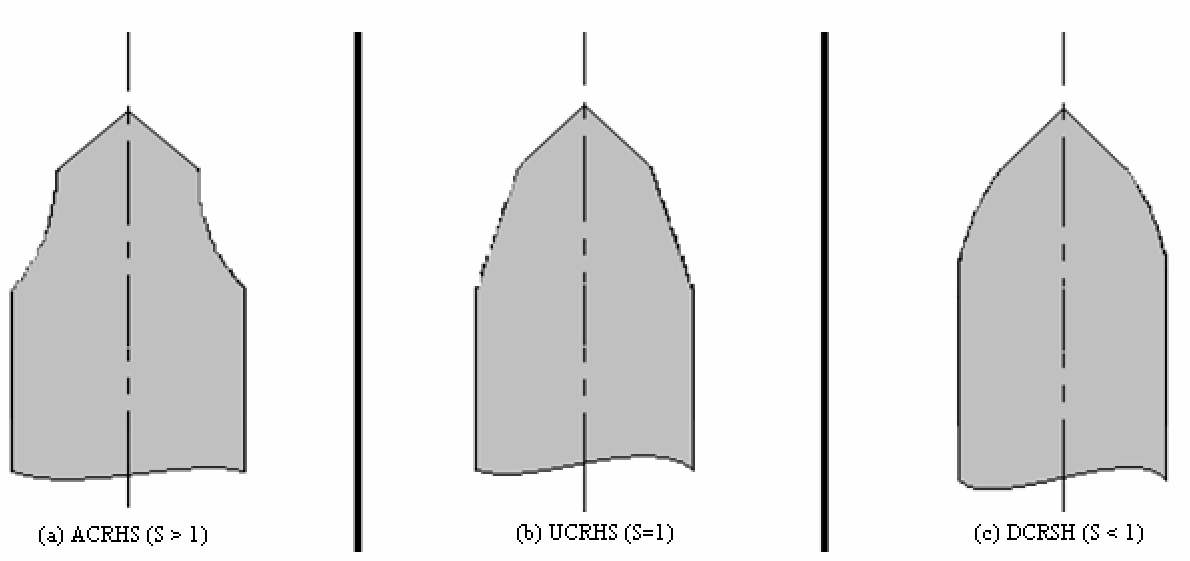

Figure 2. CRHS – Concept design of widening plug profile (S is the rate of deformation).

Table 1 Plug specifications.

Plug no.	Plug type	Deformation rate (s)	Plug diameter (mm)	Profile length (mm)	Plug profile surface area $(mm)^2$
1	DCRHS	0.9	18.0	15.442	97.028
2			22.0	16.161	101.545
3			24.0	16.597	104.283
4			28.0	17.321	108.831
5			30.0	17.749	111.523
6			32.0	18.178	114.217
7	ACRHS	1.1	18.0	15.090	94.813
8			22.0	15.799	99.274
9			24.0	16.227	101.958
10			28.0	16.940	106.439
11			30.0	17.367	109.117
12			32.0	17.793	111.798
13	UCRHS	1.0	18.0	14.992	94.195
14			22.0	15.698	98.631
15			24.0	16.119	101.276
16			28.0	16.827	105.728
17			30.0	17.250	108.385
18			32.0	17.675	111.057

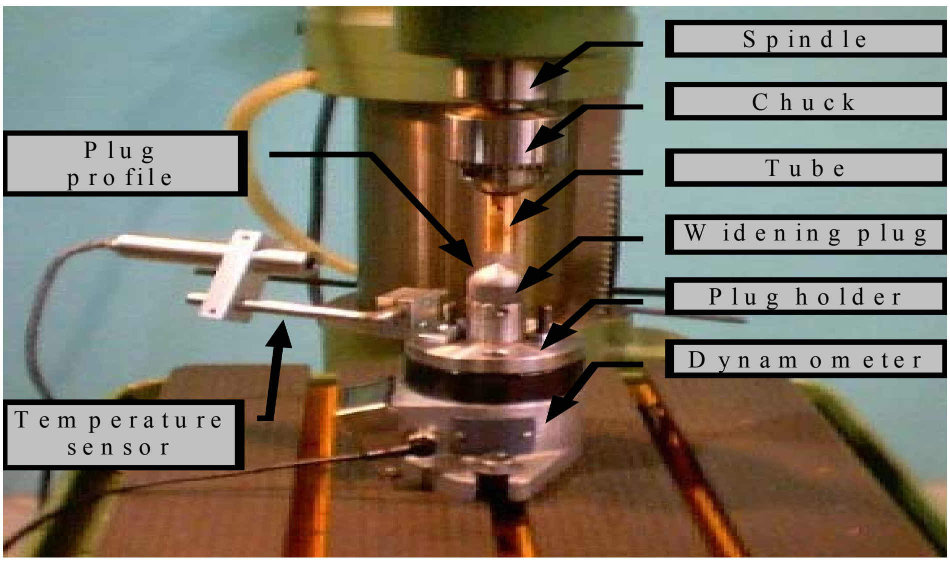

Figure 3. Experimental process set up.

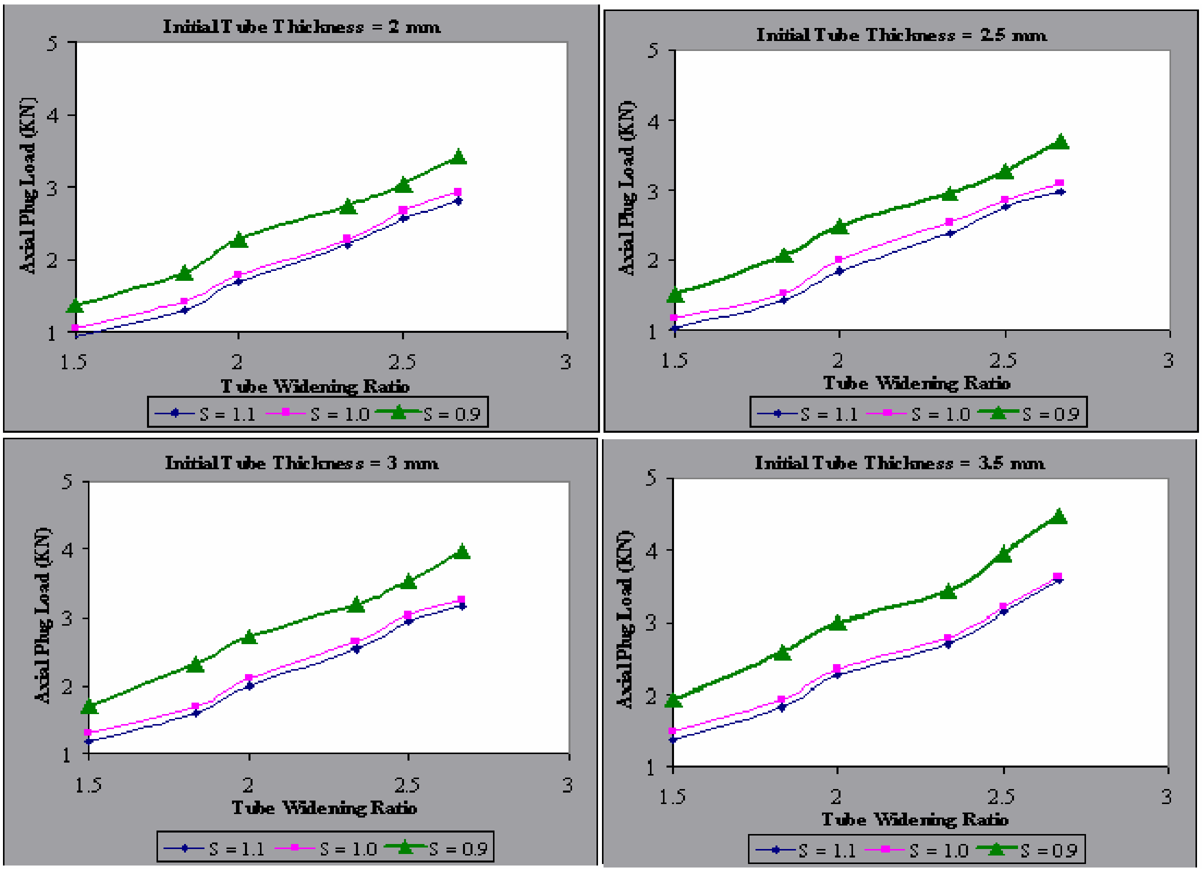

Figure 4. Relation between axial plug load and widening ratio at different tube thicknesses.

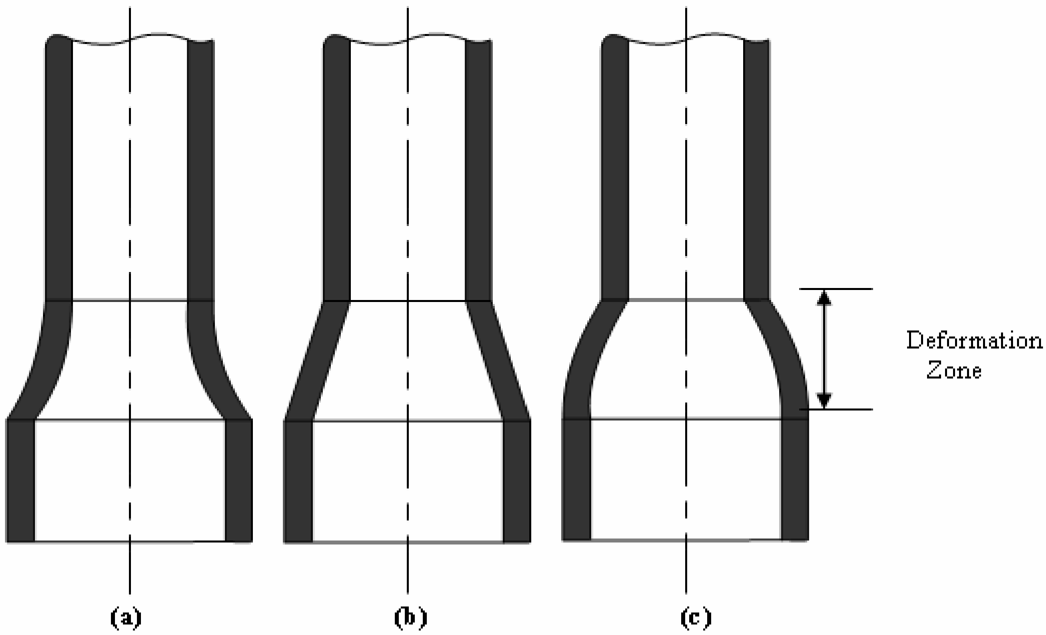

Figure 5. Mechanism of tube metal flow for different plug profiles, (a) ACRHS (b) UCRHS (c) DCRSH.

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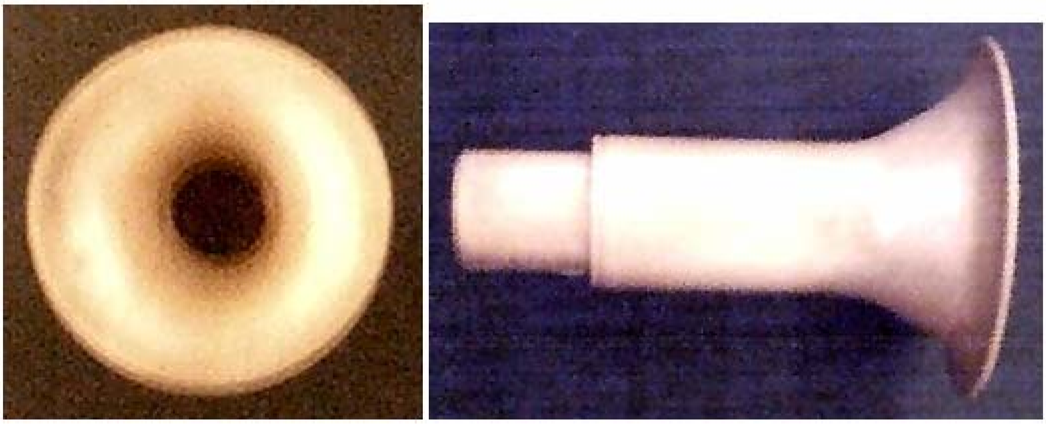

Figure 6. Round flatted flange at the tube ends: Top and side views.

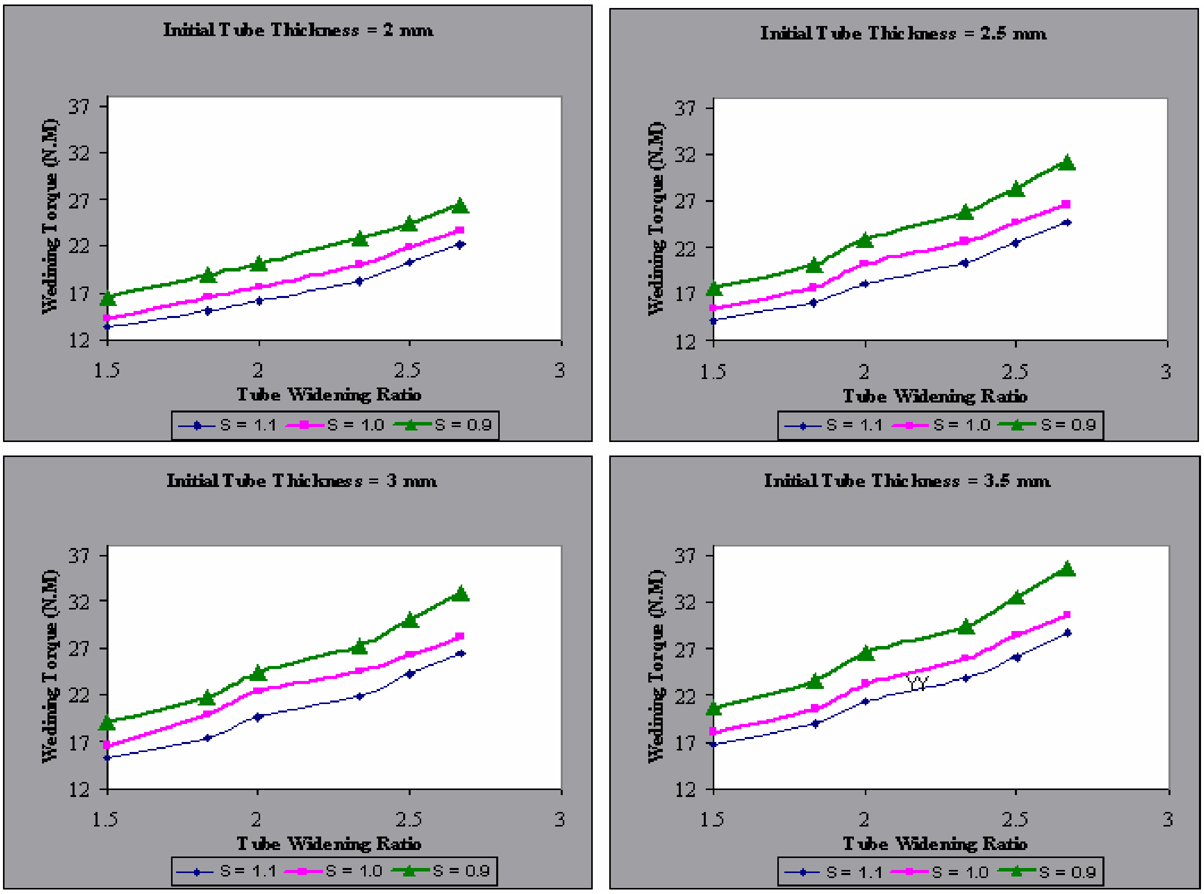

Figure 7. Relation between widening process torque and widening ratio

the same reason of increasing in material volume displaced in unit time.

It can be indicated again from Figure 6 that ACRHS plugs give the lowest level of widening torque and the DCRHS plugs give the highest due to the same reasons mentioned in the analysis of the axial plug load.

4.3. Variation of Temperature

Analysis of the axial plug load and the widening torque showed that ACRHS plugs give the lowest level of axial plug load and torque. The reason for this was that the widened tubes end experienced less metal flow displacement in the deformation zone. To verify this explanation, the temperature that results from the widening process was measured using a temperature sensor, as shown in the experimental setup in Figure 3.

Figure 8 shows the variation of temperature during the widening process relative to the widening ratios, tube thicknesses and plug profiles. As expected, the ACRHS plugs profiles gives the least amount of temperature increase compared to the other profiles.

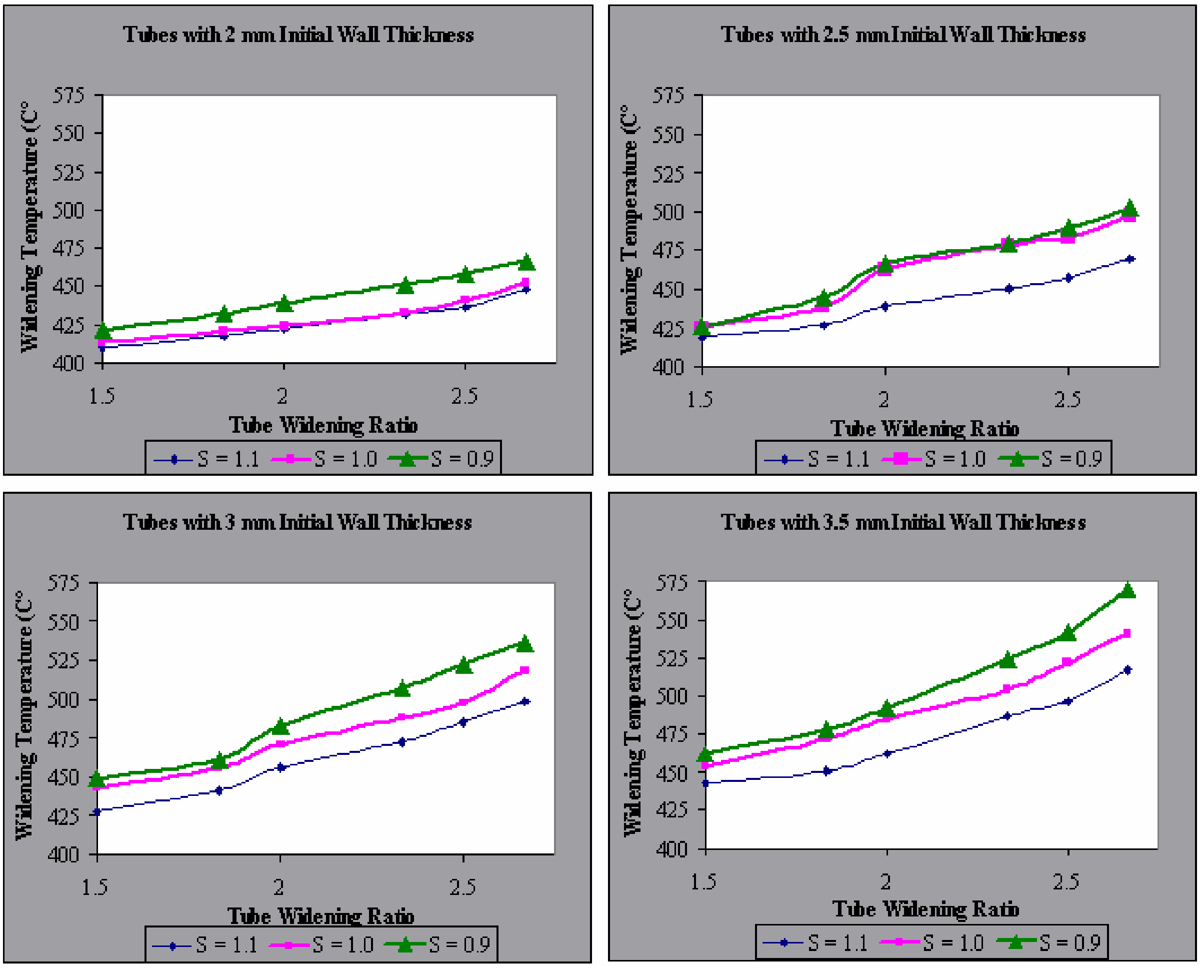

Figure 8. Temperature variation with the widening ratio for different tub thicknesses.

It has been known that one of the many factors that lead to the temperature increase in the deformation processes is the volume of the internal distortion that occurs in the deformed material. It is important to note that with large material displacement, which may be performed in such deformation process, a high quantity of the internal distortion will be deformed. This is the reason why the ACRHS plug profiles give a small increase in temperature during the process due to the small material displacement achieved with those plug profiles.

4.4. Widened Tube Thickness

Figure 9 shows the variation in the final tube thickness relative to the widening ratios, tube thicknesses and plug profiles. Note that the increase of the widening ratios leads to a high reduction in tube thicknesses. This is due to the high tube material expansion i.e. high material stretching or high incidents of strain and as a result of that high reduction in the tube thicknesses.

As expected, the ACRHS plugs profile give less reduction in the tubes thicknesses. This is again due to the less tube material displacement or material expansion in the deformation zone and as shown in Figure 5. This can be clarified from the figure, where for the highest widening ratios, the differences in tube thickness variations relative to the type of the plug profiles are well defined.

4.5. Widened Tube Quality

One of the most important requirements from any use of deformation process is to gain high quality products. This can be verified if the product has, for example, high dimensional accuracy, precise shape, and minimum internal and external defects. These three quality considerations may be simulated in the case of the widened tube ends using three parameters; the roundness of the tube end, the uniformity of the tube end thickness and the formation of tube tearing. Accounting for these quality parameters can minimise the problem and failures in pipes networks.

It has been found that the use of the concept of the Constancy of the Ratios of successive generalized Homogeneous Strain increments (CRHS) for the widening plug profiles give a good effect on these parameters. This can be seen in Figure 10, where all the plug profiles show a perfect round tube ends in addition to a uniform thickness for all tube thicknesses and widening tube ratios. An exception to this case is the case of the ACRHS plug profiles, where a round flattened flange resulted when widening ratios of 2.50 and 2.67 were attempted. Furthermore, no tearing defects occurred during the process with the used widening ratios, even with those widened tubes that have been deformed to a flattened flange.

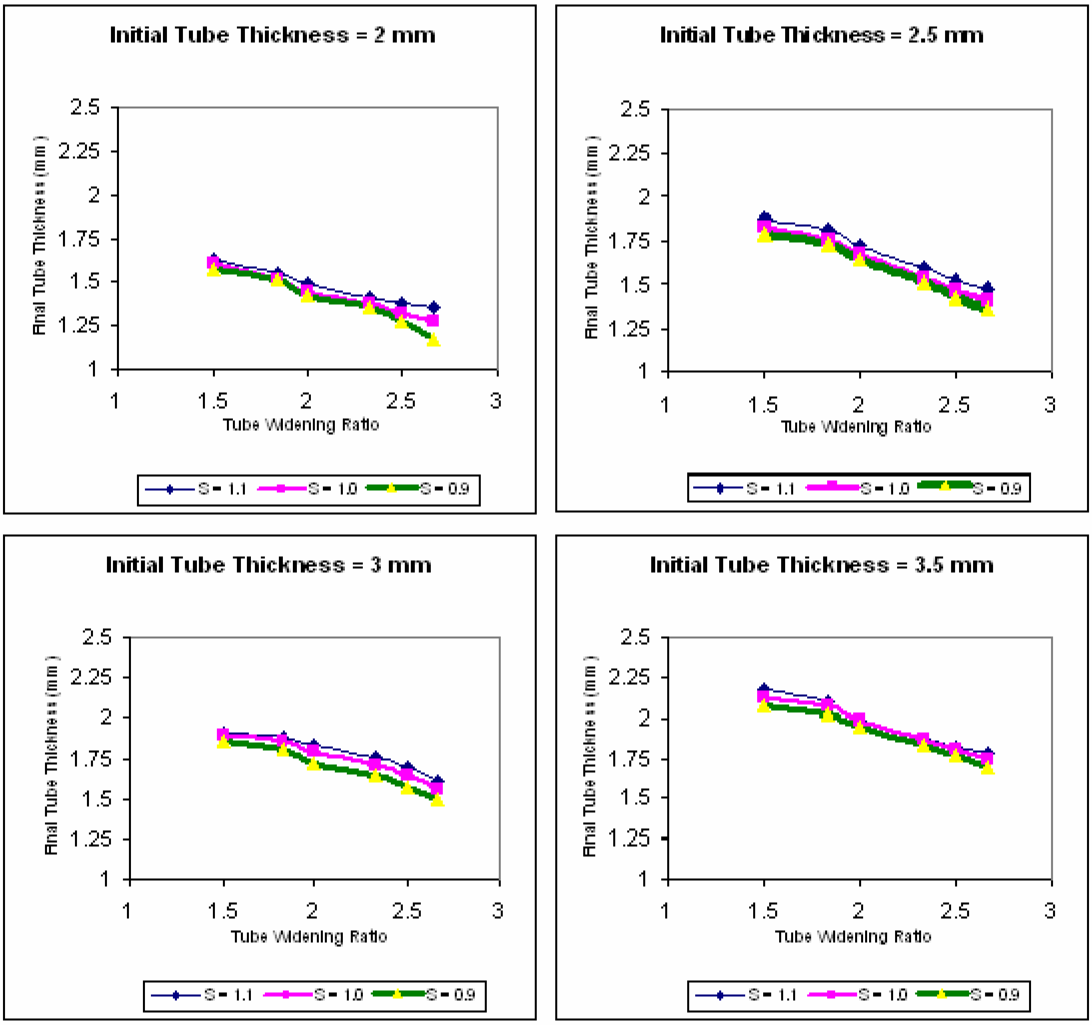

Figure 9. Relation between final tube thickness and widening ratio.

Figure 10. Widened tube ends profile: Top and side view.

5. Conclusions

The experimental results for the widening tubes end process have shown that the process parameters are completely affected by the geometry of the widened plug profile. They have also shown that the use of the concept of Constancy of Ratios of successive generalized Homogeneous Strain increments (CRHS) has significantly improved the performance of the process. It gives a maximum widening ratio of 2.67 under all the conditions selected for the process, which represents a 25% increase in the widening ratio compared to other used techniques. Adding to that, the produced widened tube ends are in high dimensional precision and uniform thicknesses without any tube wall tearing.

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