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EFFECT OF THE FRICTION AND REDUCTION ANGLE ON THE ACCURACY OF COLD DRAWING STEEL TUBES STL MODEL BASED ON FEM ANALYSIS

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Abstract

The object of the study was to create a computer model that resembles the process of cold drawing seamless steel tubes, and evaluate the influence of selected process parameters on selected final dimensions and tolerances of STL models of the tubes obtained from DEFORM simulation software. The STL models of tubes generated from the simulations were evaluated, and the effects of the reduction angle and the friction coefficient on the inner/outer diameter, inner/outer roundness and concentricity were subsequently found. It was proven that the inner and outer diameters are not influenced by different values of the friction coefficient at the same reduction angle. On the other hand, increasing value of the reduction angle affects decrease of the outer and inner diamaters after drawing. Furthermore, this experimental investigation vindicates that friction coefficient and reduction angle have the minimal impact on the inner/outer roundness and outer concentricity.

Key words

Cold drawing, tube, nib, dimensions, tolerances, simulation, Finite Element Model

INTRODUCTION

Tubes are made of different materials and by different manufacturing technologies. In addition to steel tubes, plastic tubes [1], tubes made of composite materials (e.g. carbon/epoxy composites) [2] are also known. Drawing or welding technology is used for the manufacturing of metal tubes, but hydroforming technology [3] can also be applied.

Seamless steel tubes are manufactured by the cold drawing process. As a feedstock for cold drawing process, hot rolled hollows are used exclusively. The drawing process itself consists of multiple drawing passes, either as a die drawing or plug drawing arrangement. The sinking pass usually ends the whole drawing sequence, reducing the outer diameter of the tube without altering the wall thickness [4].

Cold drawing is a widely used metal forming process with inherent advantages like close dimensional tolerances, good surface finish and improved mechanical properties of the product, as compared to hot forming processes [5]. Cold drawing process or drawing process in general has been studied by different approaches. The drawing process determined the material of the tube being drawn, the lubrication (type and method [6]), tool geometry and various process parameters, i.e. mostly die geometry, strain degree and strain rate, force conditions and conditions of friction [4], [7], [8], [9], [10].

The authors of [11] optimized the geometry of the tools through a finite element model in order to reduce the maximum level of stress when pulling tubes in one stroke during the cold drawing process of 6063 aluminium tubes. Paper [4] deals with the relationship between the tool geometry and the drawing force during cold drawing of steel tubes using numerical simulation, because reduction of drawing force leads to higher productivity and/or lower energy consumption and lower tool wear. Authors [12] describe the methodology to define friction coefficient between a tool and a forming material during tube cold draw technology process. They determined that there is linear influence between drawing force and friction coefficient.

What all those studies have in common is optimization of the cold drawing tube process using numerical simulation, because the design of optimized cold drawing by means of classical trials and errors procedures, based substantially on designers' experience, has become increasingly demanding in terms of time and cost.

From the literature surveyed it was found that the software available to carry out the computer simulation and analysis of the drawing process is e.g. ABAQUS, MSC.SuperForm, Ansys, LS-DYNA and DEFORM [13], [14], [15], [16], [17].

Based on the requirements arising from the proposed experiment, in this paper, three-dimensional (3D) axisymmetric finite element models of seamless tube cold drawing process were developed in software DEFORM-3D (Design Environment for FORMing). DEFORM-3D is a powerful finite element method simulation system designed for analysis of material flow in a wide range of forming processes [18].

This paper follows the work [7], where the authors used the DEFORM simulation software to simulate the dependence “drawing force - drawing rate” at two reduction angles (20°, 24°) and two friction coefficients (0.08; 0.12).

In the research described in this article, computer simulation including different levels of reduction angle and friction coefficient was carried out. The effect of these parameters (i.e. reduction angle and friction coefficient) on STL models accuracy were studied. The obtained models provided important contribution to the understanding of how different process parameters can affect the drawing process and the final dimensions of steel tubes. These models can be further used to perform other studies and analyses to improve the cold drawing tubes process.

MATERIALS AND METHODOLOGY OF EXPERIMENT

The initial semi-product for manufacturing of seamless steel tubes using cold drawing technology are hot rolled tubes. The dimensions of hot rolled tubes depend on the required final diameter and the wall thickness of the tube. Hot rolled tube of diameter Ø28 mm and the wall thickness of 4 mm was used for the production of the tube with required dimension of the diameter of Ø25 mm and wall thickness of 4 mm.

Ferritic-pearlitic low-carbon steel grade E235 (Yield stress Re = (235 ÷ 245) MPa, Tensile strength Rm = (343 ÷ 441) MPa, Ductility A5 = 24 %) was used for the production of the tube. Steel type E235 is appropriate for production of seamless tubes using cold drawing technology. The material of steel is without heat treatment, or the tube is after normalization annealing.

The geometry and dimension of drawing die used in the simulation are shown in Figure1.

According to the [19] the conicity of the inlet part (reduction angle) 2α = 24 to 28° is best proven for drawing dies (nibs) according to Fig. 1, i.e. the surface line is inclined to the nib axis at an angle α = 12 to 14°. At these angles, a sufficiently large cross-sectional removal is achieved, while the deformation resistance does not exceed the strength limit of the formed steel. At a higher or lower angle α, the deformation resistance increases.

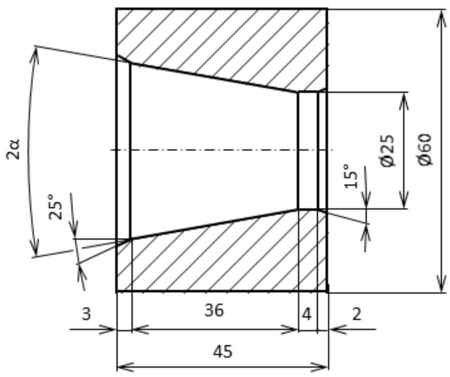

***Figure 1** Shape and dimensions of the drawing tool (according to the [7])*

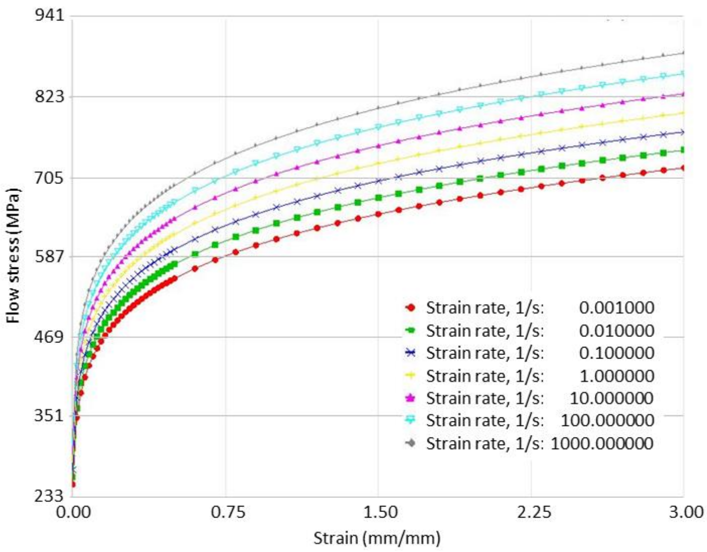

***Figure 2** Strain influence on the flow stress*

The DEFORM simulation software was used for research activities, while using FEM analysis of the tube drawing process the mentioned software allowed to evaluate the influence of selected process parameters, i.e. friction coefficient and drawing tool geometry on the final dimensions of tubes. In our case, the material model was specified using the „Flow Stress“ approach (Figure 2). Elastic properties in the material model (Young's modulus, Poisson's ratio, thermal expansion) were defined as a function of temperature.

We used a tetrahedral mesh type, and the minimal and maximal element size was 0.5 mm and 1.2 mm. It is obvious, when the model consists of more elements, that the FEM mesh is closer to the real dimensions and real shape of the evaluated object.

It was necessary to perform different variants of the FEM simulation of the tube die drawing process. The constant drawing rate (200 mm/s) was entered in the pre-processing phase and drawing tool geometry and reduction angles were chenged on four levels (Table 1).

A total number of 16 FEM simulations of cold tube drawing processes were performed.

Table 1 Friction coefficients (f) and reduction angles (2α) used for simulation	
Friction coefficient (-)	**Reduction angle (°)**
0.06	12
0.08	16
0.10	20
0.12	24

The pre-processing simulation phase required to model the shape of semi-product and drawing tool shape using CAD software. Further, the models were imported into DEFORM software in STL format. Within the next steps of simulation pre-processing, the process type, forming temperature, friction type, movement type, number of mesh elements and number of simulation steps, etc. were defined.

Further, an example of creation of pre-processing simulation phase and definition of input parameters for selected simulation of cold tube drawing process is stated below (Table 2).

Table 2 Selected input parameters for simulation of cold tube drawing process
Object name: **Semi-product – Tube** Geometry – import 3D model semi-product - Tube Object type: Plastic; Mesh - Number of elements 160000; Material: E235
Object name: **Die** Geometry – import 3D model drawing tool - reduction angle 2α=16° Object type: Rigid
Object name: **Drawing carriage** Geometry – import 3D model drawing carriage Object type: Rigid; Movement – drawing rate 200 mm/s
Ambient temperature: 20 °C Simulation Control: Number of simulation steps 700; Step increment - 0.1 mm/step Inter object: Friction - Shear 0.08 and other.

The post-processing simulation enables to depict the material plastic flow in drawing die at tube drawing process (Figure 3) and the courses of effective strain in the drawn tube.

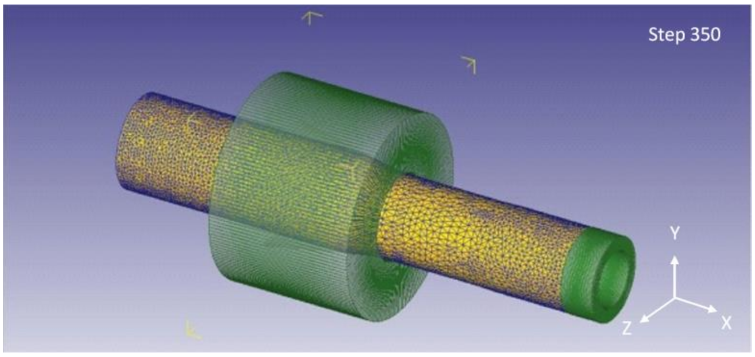

Figure 3 *Picture of simulation process in the step of 350*

The evaluation of digital models of tubes (in STL format) obtained by simulation from DEFORM software was performed in GOM Inspect Professional v7.5 SR2 software. The measured and evaluated outputs were inner/outer diameter, inner/outer roundness and outer concentricity. Those are the most important parameters according to the geometrical product specifications and tolerances of the cold drawing tube.

RESULTS AND DISCUSSION

It was determined that the friction coefficient has not important influence on the dimensional and geometrical parameters, as seen in Figure 4. The values were changing on the second decimal place and even not significantly.

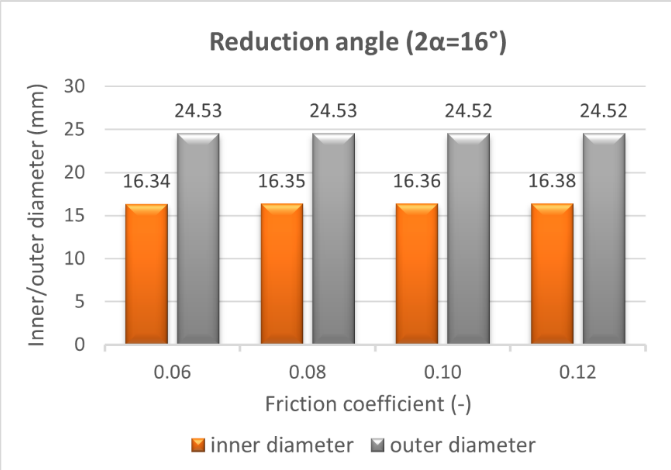

Figure 4 *Friction coefficient influence on the inner and outer diameters for reduction angle of 16°*

Similar evolution of the results was achieved for all used reduction angles. Values of roundness and concentricity did not change in many cases (Fig. 5) with increasing the friction coefficient.

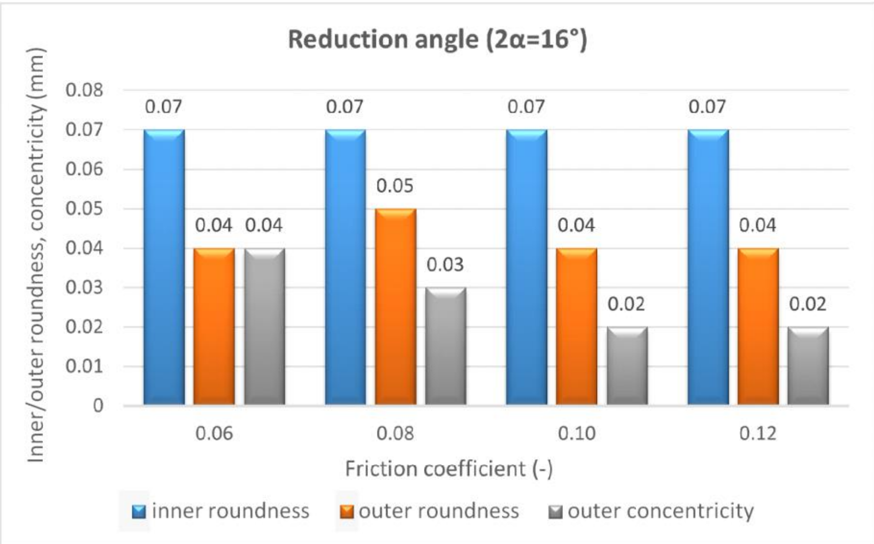

Figure 5 *Friction coefficient influence on the inner and outer roundness and concentricity for reduction angle of 16°*

More significant results were achieved in the experimental investigation of the effect of the reduction angle on the dimensional and geometrical parameters. Differences between individual reduction angles were in tenths of millimeters (Figure 6).

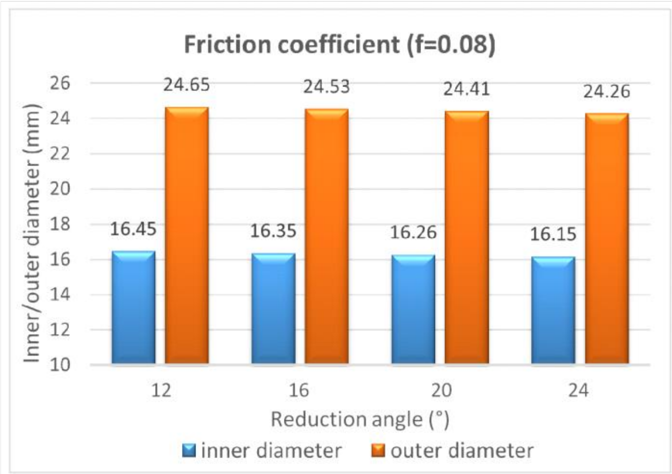

Figure 6 *Reduction angle influence on the inner and outer diameter for friction coefficient of 0.08*

It is obvious that the inner and outer diameters of the tube decrease with increasing the reduction angle. The higher the value of the reduction angle, the lower the value of tube diameter. The larger difference in diameters may be due to the use of a drawing tool used to simulate drawing, which is preferably applied to mandrel drawing of tubes.

However, the influence of the reduction angle on the inner and outer roundness and concentricity was not proven (Figure 7). The difference between the lowest and the highest deviation values according to the reduction angle changes was 0.03 mm.

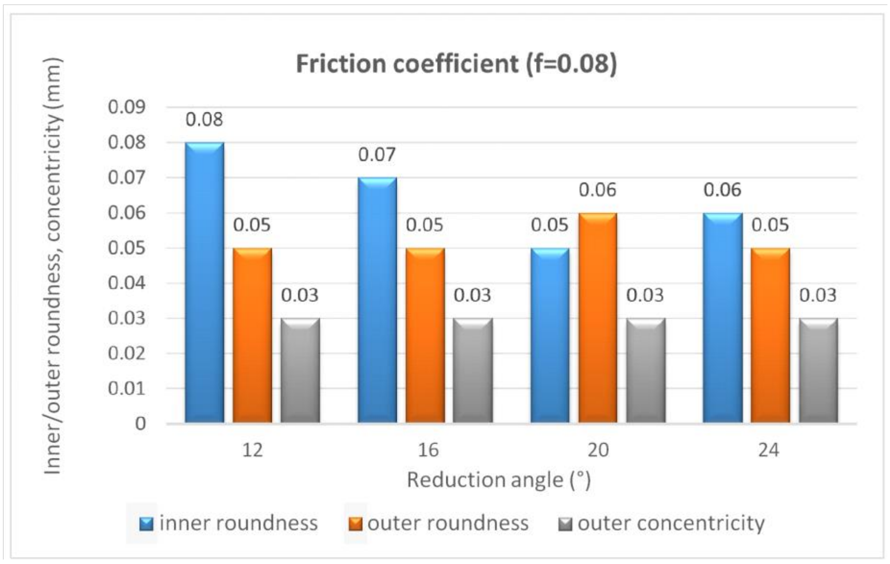

Figure 7 *Reduction angle influence on the inner and outer roundness and concentricity for friction coefficient of 0.08*

CONCLUSION

This paper presents the results of simulations of cold drawing of tubes, which were performed using the DEFORM simulation software. The drawing die (nib) was used at different reduction angles (12°, 16°, 20°, 24°). Drawing was performed at a constant drawing rate (200 mm/s = 12m/min) and at different friction coefficients (0.06; 0.08; 0.10; 0.12).

Based on the obtained simulation results, it was found that, at the same reduction angle, the influence of different values of the friction coefficient on the change of the inner and outer diameter of the resulting tube was minimal (Figure 4).

At a constant friction coefficient and increasing value of the reduction angle (12°, 16°, 20°, 24°), the outer and inner diameters of the tubes decrease after drawing (Figure 6). This means that the deviation from the required final dimension Ø25 mm increases with increasing value of the reduction angle (12°, 16°, 20°, 24°). The author [13] also points the fact of the difference between the diameter of the drawing die (nib) and the diameter of the final tube when cold drawing using a conical die.

Furthermore, it was found that the inner/outer roundness and outer concentricity change only very minimally, which is due to the change of the friction coefficient and the reduction angle (Figure 5, Figure 7).

It could be assumed that using a denser mesh will affect dimensional and shape accuracy; however, this experimental investigation did not focuse on the comparison of the FEM meshes of different amount of the elements creating the model.

As this is a base research in the field of cold drawing of tubes, the dimensions of the die are designed in various modifications. The results of the base research have not been validated in practice, as these are the initial simulation studies within the given research in the field of geometric dimensional stability. The chosen method of drawing in the experiment was not selected for the common conditions of tube drawing in operating conditions (the type of drawing die presented in the current paper is mainly used when drawing the tubes with an internal tool - mandrel), which will also contribute to the new knowledge in the field of geometric stability of the tube dimensions. After validating the results in practice, the conclusion of the study will be a technical explanation and comparison of two different types of drawing dies with different methods of the tube drawing technology. However, it should be noted that the results were obtained under ideal conditions. The final dimensions of the drawn tube are influenced by many technological factors (e.g. drawing rate, deformation rate, drawing method, etc.) as well as the human factor.

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