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VALIDATION OF RESULTS OF TWO DIFFERENT REDUCTIONS FOR PRECISION SEAMLESS COLD DRAWN TUBES

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This paper deals with the comparison of the seamless pulling process of precision seamless tubes using two different reductions from the viewpoint of geometrical stability using computerized tomography, from the point of view of mechanical properties, from the point of view of the surface temperature in the arrangement of the tribological tube-tool pair. Validation of the pipe drawing process also took place based on the finite element method in the simulation program DEFORM 3D. From the point of view of production rationalization, it is necessary to analyze stress and deformation states at different input dimensions for a particular final dimension for a given drawing method, in this case, a drawing whiteout plug method was used.

Key words: steel tubes, cold drawing, mechanical properties, computer tomography, numerical simulation

INTRODUCTION

Manufacture of precision tubes has technological node is given a precisely defined technology for the production of a precision tube according to the proposed criteria. According to Figure 1 the individual parameters must be follow in the individual nodes, such as, for example, the exact geometry of the tip (length, diameter) and process (hot and cold swaging) must be followed according to the process. When drawing tubes, the distribution of individual strokes according to the reductions and the need for heat treatment must be respected. The whole process is very complex and its proposal is a basic condition for the final quality of the oven and the rationalization of production. An important factor for the determination of limit deformations is the need to focus on technological parameters, operations and the shape of tools in terms of their geometry when cold forming [1].

The process of manufacturing cold-drawn seamless tubes (Figure 1). The rationality of the calibration will therefore depend on the use of the maximum allowable elongation coefficients for each draw. From the point of view of possible intensification and cost savings, the calculation currently includes the determination of the number of drawings according to the drawing method and the determination of the geometrical dimensions of the tubes after each drawing. When calculating dimensional calibration by the basic factor determining the permitted degree of deformation, the material strength is *R*m. Consumption of material depends on the number of waveforms and their interrelationships. If the deformation mode of the tube drawing is properly organized, it must ensure production with a minimum number of drawings and minimum material consumption.

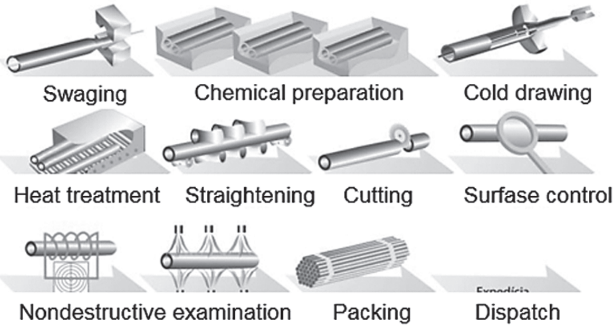

Figure 1 Diagram of production flow of cold-drawn steel tubes

EXPERIMENTAL MATERIAL

The E235 steel grade was selected for the experiment (Table 1). It is very important to add that this material is supplied to the drawing process itself as a rolled pipe, which is in keeping with the technological process, i. rolled in the austenite zone by properties similar to the ignited material. However, due to the possibilities of modification and optimization of the drawing process, it is necessary to normalize the material after rolling in order to achieve properties that will withstand more stress and in which we can achieve better conditions at the expense of plasticity at maximum limit states.

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Table 1 **Chemical composition of E235 steel grade (acc. to STN 411353) / wt.%**

C	Mn	Si	P	S
0,09	0,42	0,20	0,010	0,008
Cu	Cr	Ni	Al	Sn
0,14	0,05	0,07	0,022	0,011

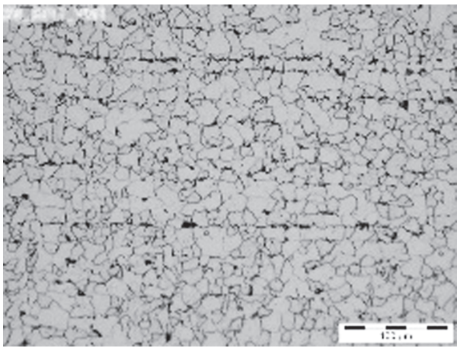

Figure 2 Microstructure after rolling and normalizing - longitudinal section

The analysis of the mechanical properties and the formability of the materials studied by means of a basic tensile test (determination of plasticity characteristics and indicators) and technological tests is a basic prerequisite for the determination of limit deformations. In Figure 2 is a microstructure of the input preform in the post-rolling state and the normalization annealing.

The microstructure is ferritic-perlitic with an average ferrite size of 7,5 µm. The microstructure exhibits homogeneity in the size of the ferrite grain along the thickness of the wall. In the longitudinal direction, there is a marked linearity of the perlitic phase arrangement. It should be reminded that the starting state of the microstructure impacts on the possibilities of limit states of deformation in individual draws. Mechanical properties of material E235 according to EN411353 are $R_{e\ min}$ 235 MPa R_m 343-441 and A_{5min} 25 %.

TECHNOLOGY

All current technology consists of 5 sequences, 7 draws. The analysis in this article focuses on the latest trend, the comparison with current technology consists of a change of the previously set technology and two different alternatives of the new proposed technology. With the original drawing technology of ∅ 8 x 1 mm size to ∅ 6 x 1 mm, an alternative of ∅8 x 0,95 mm was chosen in the new proposed technology and ∅ 9 x 0,95 mm to ∅ 6 x 1 mm (Table 2).

Table 2 **Description of the original and proposed drag-and-drop technology**

Original technology						
Pass	Feedstock dimensions / mm		Tube dimensions /mm		Reduction / %	Extension / mm
	OD	WT	OD	WT		
1	8	1	6	1	28,57	1,34
Proposed technology						
Pass	Feedstock dimensions/mm		Tube dimensions/mm		Reduction / %	Extension / mm
	OD	WT	OD	WT		
1	8	0,95	6	1	25,35	1,34
1	9	0,95	6	1	34,62	1,53

O.D. – Outer diameter / mm W.T. – Wall thickness / mm

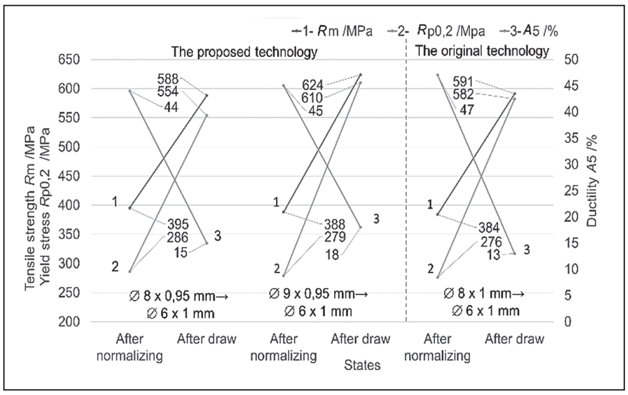

Figure 3 Mechanical properties by a state

ANALYSIS OF MECHANICAL PROPERTIES

The analysis of the mechanical properties results in the individual samples after sampling showed optimization of the technology and the limit of the limitations that can be determined in the future for individual cross-sectional changes based on simple measurements of the basic material properties and the behavior of the individual reductions due to cross-sectional change and drawing. All mechanical properties are on input materials and the input preform in the condition of material after the normalization annealing. This means that the post-rolling structure was heterogeneous and was subsequently homogenized by subsequent heat treatment. The mechanical properties described in Figure 3 are broken down according to the individual state according to the new proposed technology.

For strength properties, our strengths and tensile strengths increased on average by 200 MPa. With plastic properties, the difference between the heat treatment state and the deformed state is about 20 % on average. These values are consistent with values that correspond to the norm.

Measurement of the geometric dimensions of the drawn tube by CT (Computer Tomography)

Reverse Engineering is a process of generating a computer digital model of an existing real object by means of a suitable computer-aided technology [4]. Evaluation of the final dimension was evaluated by computerized tomography. These are modern methods of measuring shapes and geometric stability of dimensions used in metrology at a computer tomography accuracy level of from 0,003 to 0,3 mm. The dimensional and shape stability of the required dimensions of the steel pipes has a major impact on the further treatment of the process of the tubes (second production). Equivalent of tube (sample) analyzed in experiments is using Diesel engine injection units. For example, Cold bending of metal tubes is very important production method considering that metal tubes are widely used in a great variety of engineering products, such as automobile, aircraft, air conditioner, air compressor, exhaust systems, fluid lines [3]. The precision tubes obtained can now be used in subsequent hydroforming process, producing vital parts especially for automotive industry [5]. Tolerances of the precision tubes are in accordance with the appropriate dimensional tables of standards. Usual value for the outside diameter (OD) is less than 0,5 % of OD in no heat treatment process used. For the heat-treated tubes, tolerance values are depended upon the relation of the wall thickness and the tube diameter (WT/OD) and are larger (up to a single or twofold). In tolerances of the outside diameter (OD) the allowed deviation of circularity is included. Eccentricity of precision tube is included in the wall thickness tolerance. Two experimental samples were received for the measurement, which were subjected to a drawing process of ∅ 8 x 0,95 mm and ∅ 9 x 0,95 mm. The final dimension is ∅ 6 x 1 mm for both samples. In Figure 4 and Table 3 are shows the measurement and evaluation of the samples.

It state that the final dimension at two different input dimensions to the final pitch ∅ 6 x 1 mm is within the tolerance band ∅ 8 x 0,95 mm for the outside diameter of + 0,06 mm and the inside diameter + 0,03 mm, and with dimension ∅ 9 x 0,95 mm for outer diameter of + 0,04 mm and internal diameter + 0,05 mm.

Table 3 **Measurement and evaluation of the sample after drawing from the dimension ∅ 8 x 0,95 mm / ∅ 9 x 0,95 mm to ∅ 6 x 1 mm**

Drawing	8 x 0,95/9 x 0,95 → 6 x1		
	Nominal / mm	Actual / mm	Dev. / mm
ID -160	+4,00 /+4,00	+4,03/+4,04	+0,03/+0,04
OD-160	+6,00/+6,00	+6,06/+6,05	+0,06/+0,05
ID-120	+4,00 /+4,00	+4,03/+4,04	+0,03/+0,04
OD3-120	+6,00/+6,00	+6,06/+6,05	+0,06/+0,05
ID-80	+4,00 /+4,00	+4,03/+4,04	+0,03/+0,04
OD2-80	+6,00/+6,00	+6,06/+6,05	+0,06/+0,05
ID-40	+4,00 /+4,00	+4,03/+4,04	+0,03/+0,04
OD1-40	+6,00/+6,00	+6,06/+6,05	+0,06/+0,05

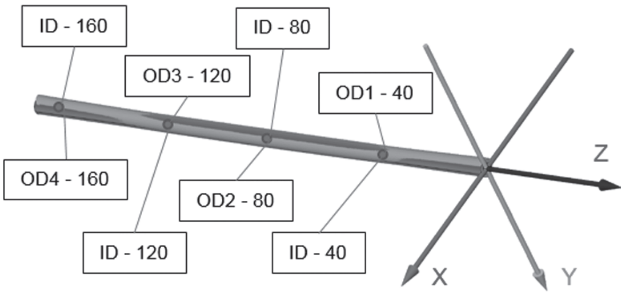

Figure 4 Shown measurement and evaluation of the sample after drawing from the dimension ∅ 8 x 0,95 mm to ∅ 6 x 1 mm

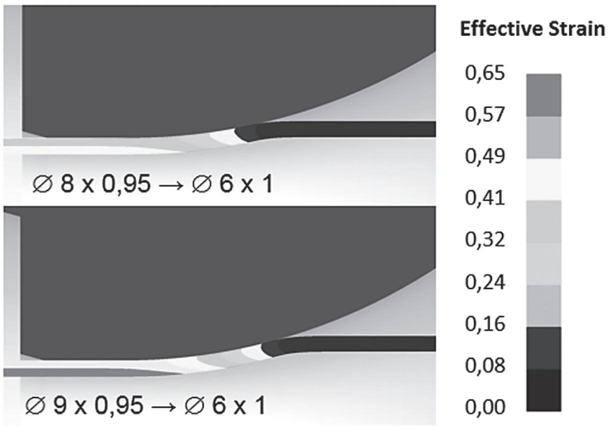

Figure 5 Strain effective

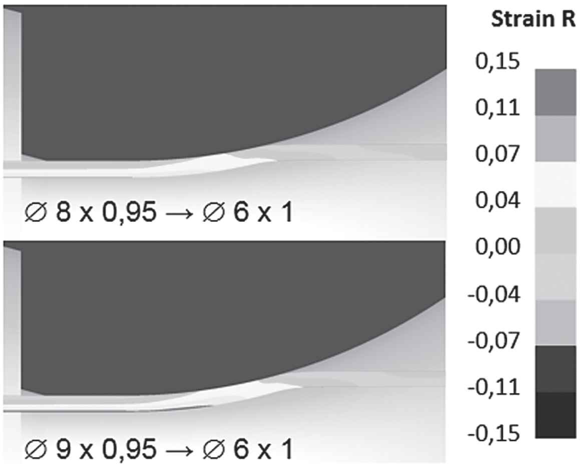

Figure 6 Deformation in the radial direction

VALIDATION OF INTENSE DRAWNS USING THE DEFORM 3D SIMULATION SOFTWARE

From the intensity distribution Figure 5 (strain effective) deformation, it can be seen that higher values on the inner surface of the tube have been recorded at both draws.

By drawing ∅ 9 x 0,95 mm → ∅ 6 x 1 mm the values were almost 40 % higher compared to the pull ∅ 8 x → ∅ 6 x 1 mm. In the radial direction (R), the effect of the tensile deformation (Figure 6), which is responsible for the thickness of the tube wall by 0,05 mm, is visible.

In the tangential direction (theta) (Figure 7), higher tensile strain values of ∅ 9 x 0,95 → ∅ 6 x 1 were recorded, since a higher reduction in the external diameter was chosen by drawn. In the axial direction (Z) (Figure 8), strain deformation values were recorded after drawing ∅ 9 x 0,95 → ∅ 6 x 1 in the interval $\varepsilon = < 0,438; 0,5 >$. By drawing ∅ 8 x 0,95 → ∅ 6 x 1, 37 % lower values were recorded in the axial direction. The effective stress values (Figure 9) in the deformation band move in both cases around $\sigma = 500$ MPa. The difference is seen behind the die, where the tube is intensively stressed by the tension.

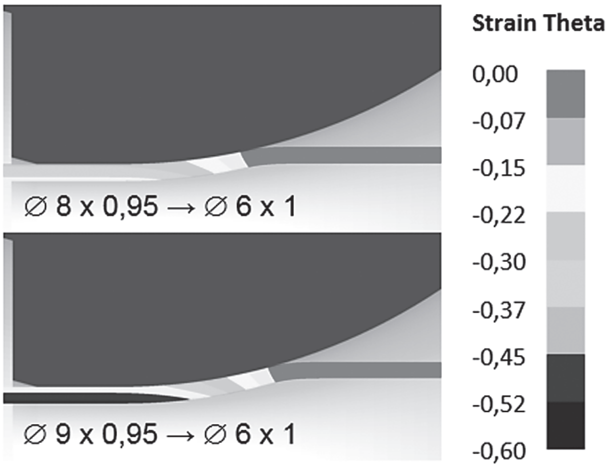

Figure 7 Deformation in the tangential direction

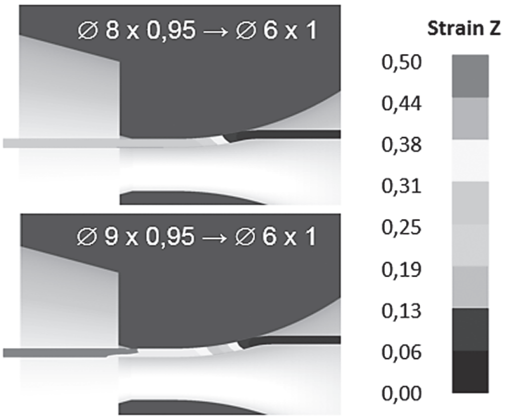

Figure 8 Deformation in the axial direction

CONCLUSIONS

Particular analyzes have shown the possibilities of making a precision tube by means of hollow sinking drawing process. The resulting properties of seamless tubes depend on a large number of factors. One factor is also the geometric instability in the various phases of the production process. Geometric instability is closely related to the technological process of tube production. Detailed development and optimization of the production process technology, which is composed of individual operations that affect geometrical dimensional instability and individual thermomechanical conditions, need to be further addressed. In terms of rationalization, it is important to know the limit states of deformations. In the case of forming materials, focal points of plastic modification may occur locally where the transformations reach their max. and are in view of the possible failure of the tube in further processing by critical locations even if the average value of the transformation determined by the change of shape and dimensions does not exceed the limit value of the transformation for the material and the given operation forming. The uneven distribution of the deformation in the tube volume make the inhomogeneity of the oven properties. The uneven distribution of cold formed cold forming is caused by external contact friction between the molded material and the forming tool as well as a certain unevenness of the mechanical properties of the molded material. Rationalization of production requires the analysis of tautness and deformation states in various tube drawing methods (e.g. pulling on the cylindrical mandrel, pulling on the floating plug, pulling on the rod, hollow sinking drawing process – without plug), with particular attention being paid to the possible development of final products (precision tubes) by increasing the intensity of individual drawings (max. reduction and removal) and the possibility of realizing multistage drawing without annealing (recrystallization is finished when symmetrical grains replace an output deformed structure [6]).

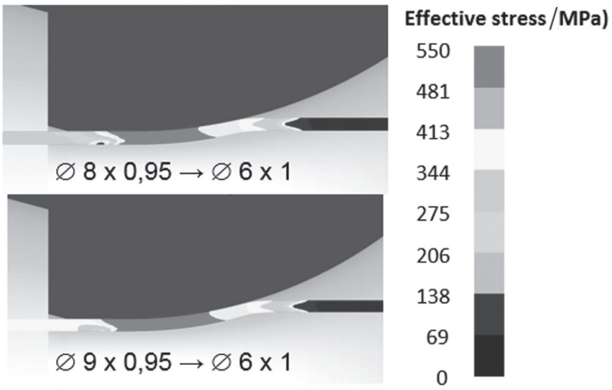

Figure 9 The effective stress

Acknowledgements

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Note: Pavol Buček is responsible for English language, Podbrezová, Slovakia