MECHANICAL PROPERTIES AND MACROSCOPIC DEFORMATION OF PRECISION SEAMLESS TUBES DURING COLD DRAWING

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ABSTRACT: This paper deals with the mechanical properties and macroscopic deformation of precision seamless tubes during cold drawing, using two different methods in one technological sequence. The tubes were cold-drawn in five technological sequences, undergoing seven drawing passes in total. After each sequence the intermediate annealing took place. The main goal of the experiment was to evaluate the initial state of ∅ 31.8 x 2.6 mm hot-rolled tube made of E235 steel grade that was subsequently cold-drawn to the final dimension of ∅ 6 x 1 mm while using specified reductions according to technological standards. Finally, the influence of selected reductions and the drawing technology itself on mechanical properties and macroscopic deformation of the material was evaluated. (The experiment described in this paper is a part of the research project aimed at whether it is possible to determine input technological parameters so that the tube production process would be more effective.)

KEY WORDS: mechanical properties, macroscopic deformation, reduction.

1 INTRODUCTION

Cold drawing technology used for manufacturing of precision seamless steel tubes in Železiarne Podbrezová depends on many factors, two of which are the initial and the final tube dimensions. Proper selection of area reductions is therefore a crucial task as the improper reduction sequence may lead to excessive straining, possibly causing cracks or even material failure. In plug drawing technology, the inner diameter of the tube takes the exact dimension, while the wall thickness is being reduced. Cold drawing using a fixed plug is a versatile technology, boasting high productivity and rather low demands on the drawing tools. As the main tool, the reducing die is used. A cylindrical plug, being fixed on a mandrel, is inserted into the die orifice. The proper alignment of the die and the plug is necessary for attaining the correct dimensions of the tube after drawing and also for trouble-free drawing in general. Forming tools are illustrated in Fig.1.

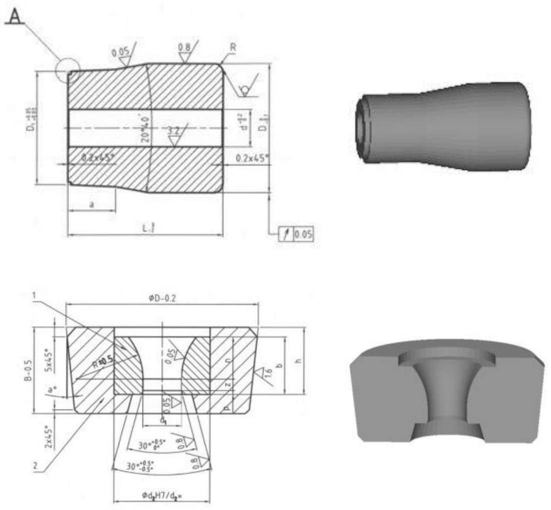

Figure 1. Forming tools (die and plug)

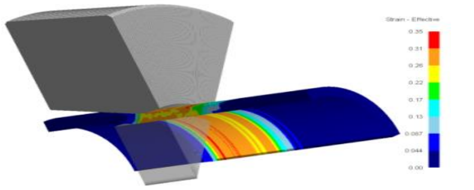

Figure 2. Illustrative example of tube drawing simulation in DEFORM 3D (the plug drawing technology)

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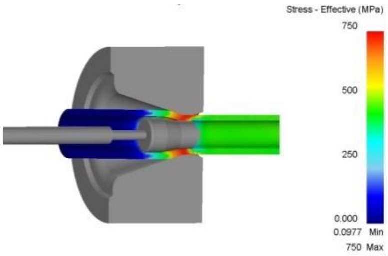

Figure 3. Illustrative example of tube drawing simulation in DEFORM 3D (the plug drawing technology)

Volume drawing of seamless tubes on drawbenches causes:

- a change of diameter,
- a change of wall thickness,
- a change of length,
- a change of cross-section shape,
- an improvement, reduction of shape and dimension deviations,
- a change of mechanical properties,
- an improvement of surface quality,
- a change of shape in the longitudinal diameter

Drawing of tube on mandrel - tube drawing on cylindrical mandrel provides a calibration of the internal diameter and reduction of the wall thickness. Drawing on a firm cylindrical mandrel has a wide application because high productivity is reached by use of simple tools and the tube quality is very high. The die drawing technology - the process of drawing is applied in cold tube drawing in connection with a drawing on mandrel.

2 MATERIAL

In this experiment, steel grade E235 (ferritic-pearlitic carbon steel, see Tab. 1) was selected; as a feedstock for cold drawing passes, hot rolled tube with the dimensions of ∅ 31.8 x 2.6 mm was chosen. Mechanical properties of E235 steel according to STN 411353 are as follows: yield strength Re = 226 MPa, tensile strength Rm = (343 ÷ 441) MPa, and ductility A5 = 24 %.

Table 1. Chemical composition of E355 steel grade (acc. to STN 411353) in wt.%

Chemical composition	Min	Max
C	0	0,090
Ni	0	0,060
Mn	0	0,420
Mo	0	0,020
Cr	0	0,060

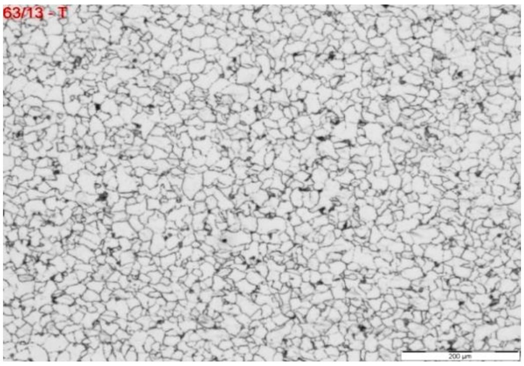

Figure 4. Microstructure of steel grade E235.

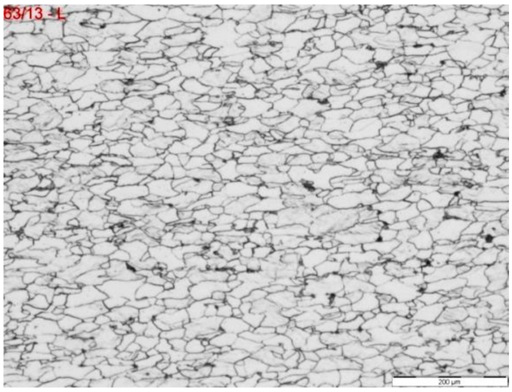

Figure 5. Microstructure of steel grade E235 after rolling in the cross sectional direction.

3 TECHNOLOGY

The main production steps for tube cold drawing in Železiarne Podbrezová are as follows [4]:

- feedstock pre-processing (hot rolled tube ∅ 31.8 x 2.6 m)
- cold and hot pointing of the tube ends (target diameter 21 mm)
- chemical treatment of the tube (pickling, phosphating, lubrication)
- cold drawing Table 2 for details Technological parameters, with 1st and 2nd drawing sequences using plug drawing passes and 3rd, 4th and 5th drawing sequences using die drawing passes
- intermediate annealing and final annealing in protective atmosphere
- final conditioning
- surface inspection, packaging, rust-proofing
- dispatch

Cold drawing technology in a nutshell is illustrated in (Fig.6).

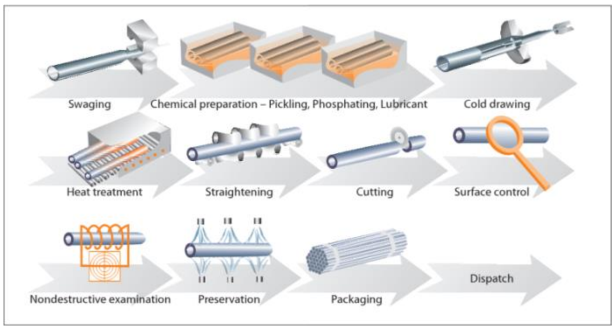

Figure 6. Cold drawing technology in a nutshell

The final tube area reduction for three-pass technology (from ∅ 31.8 x 2.6 mm to ∅ 6 x 1 mm) makes 93 %, the number which was subsequently divided among seven passes (Table 2). The calculation of the cross sectional area reduction has been done according to the formula (1):

$$\text{Reuction } r = S_r/S_0\ 100\ [\%] \quad (1)$$

$$S_R = S_0 - S\ [mm^2],$$

Where:

S_0 – tube area before drawing [mm^2],

S – tube area after drawing [mm^2].

For the 1st pass and the first drawing sequence, the reduction of cross-sectional area was 32 %; the 2nd pass in the same drawing sequence gave the area reduction of 33 %. For second drawing sequence, the 1st pass and the 2nd pass gave the area reduction 26 % and 41 %, respectively. For the 3rd, the 4th, and the 5th drawing sequence, only one pass per sequence was done, giving 32 %, 33 % and 29 % reduction of cross-sectional area, respectively.

The precision tubes produced can now be used in subsequent hydroforming process, producing the vital parts especially for automotive industry.

Table 2. Technological parameters for experimental tube drawing

Seq	Pass	Feedstock dimension O.D.	W.T.	L	Tube dimension O.D	W.T	L	R
1	1	31.8	2.6	6500	28	2	9242	32
	2	28	2	9242	25	1.5	13383	32
2	1	25	1.5	13383	22	1.3	17984	26
	2	22	1.3	17984	18	0.9	30056	41
3	1	18	0.9	30056	12	1	43844	32
4	1	12	1	43844	8	1	65540	33
5	1	8	1	65540	6	1	91560	29

4 MECHANICAL PROPERTIES

Static tensile test is a basic mechanical test originally designed to become the widespread and known testing method for evaluating the mechanical properties of metallic materials. The law of geometrical similarity is kept with axis draw load for geometrically similar prismatic testing bodies with different sizes. According to EN 10305-1 the required mechanical properties for the steel E235 +C (i.e. with no heat treatment after final cold forming) are as follows: Rm ≥ 480 MPa and A5 ≥ 4 %. Finally, all mechanical properties of the E235 steel tube are summarized in Fig.7 to Fig.16. [4, 5, 7] .

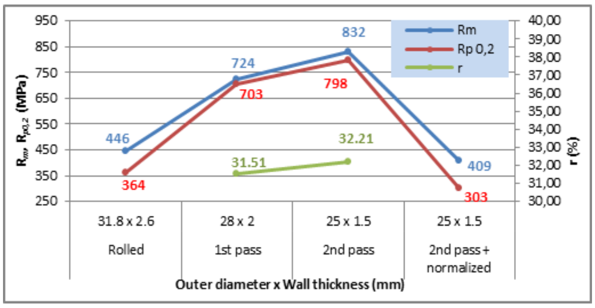

Figure 7. Mechanical properties based on tensile testing according to STN EN 10002-1 in depending on the reduction for 1st pass.

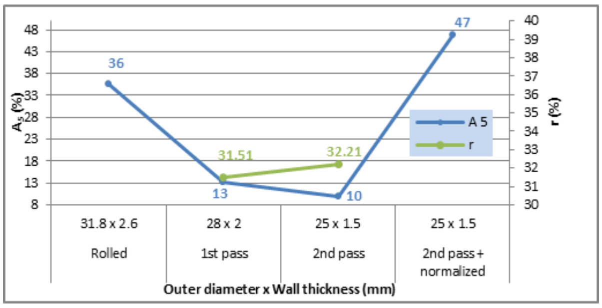

Figure 8. Dependence of ductility by reduction for 1st pass.

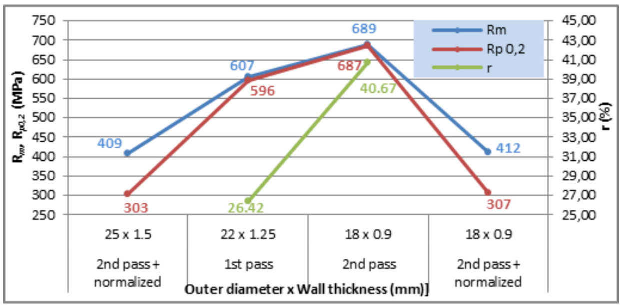

Figure 9. Mechanical properties based on tensile testing according to STN EN 10002-1 in depending on the reduction for 2nd pass.

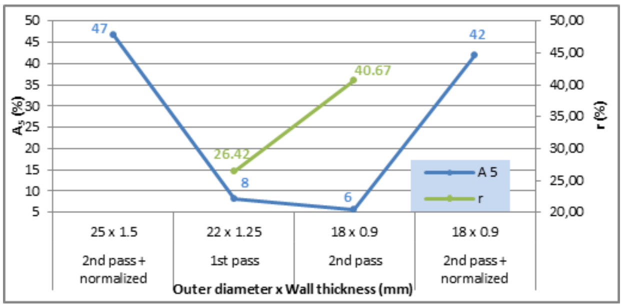

Figure 10. Dependence of ductility by reduction for 2nd pass.

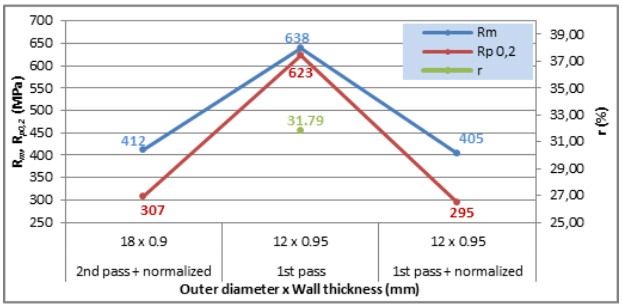

Figure 11. Mechanical properties based on tensile testing according to STN EN 10002-1 in depending on the reduction for 3rd pass.

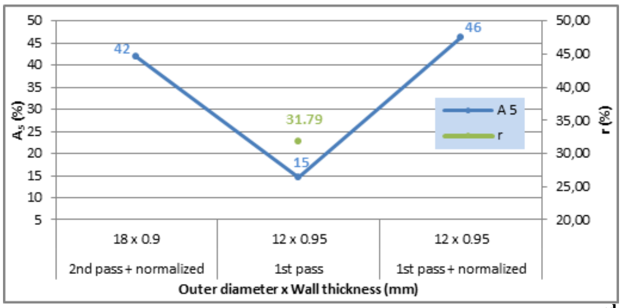

Figure 12.Dependence of ductility by reduction for 3rd pass.

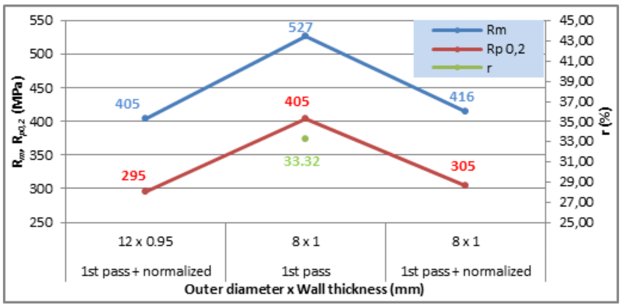

Figure 13. Mechanical properties based on tensile testing according to STN EN 10002-1 and depending on the reduction for 4th pass.

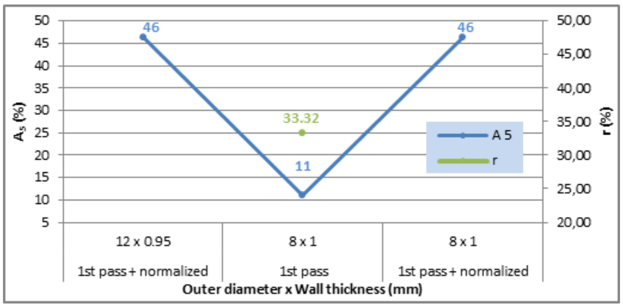

Fig.14 Dependence of ductility by reduction for 4th pass.

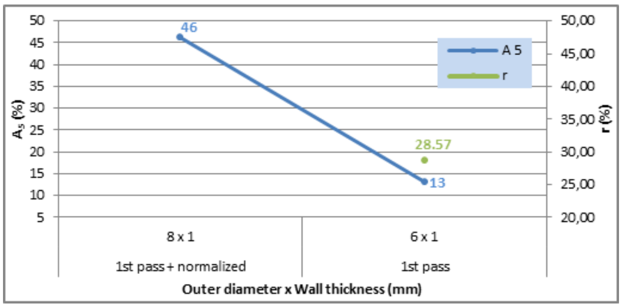

Fig.15 Mechanical properties based on tensile testing according to STN EN 10002-1 and depending on the reduction for 5th pass.

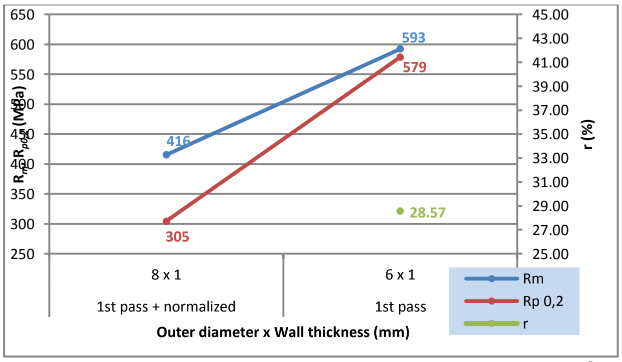

Fig.16 Dependence of ductility by reduction for 5th pass.

5 DISCUSION

In Fig. 7. is illustrates the 1st sequence in which they were implemented two passes. It is seen as influenced by size reduction of the individual mechanical properties. After the 1st and 2nd pass mechanical properties are have increased to the values shown in the graph. Elevated value were due to the dislocation reinforcing of materials. After the individual draws followed by recrystallization annealing. The ductility (see. Fig. 8) after draws decreased from 36% after the 1st pass to 13%, and after the 2nd pass to 10%. After recrystallization annealing to us ductility increased to 47%. In Figure 9 are graphically illustrated another sequence which describes the mechanical properties after two passes and after recrystallization annealing. Mechanical properties are rising due to the exhaustion plastic properties. In Fig. 10 the ductility after draws decreasing and after recrystallization annealing reached value 42%. In Figure 11 are illustrated mechanical properties after the 3rd sequence, which consisted of one draw. At reduction 31.79% was the values of Rp0.2 and Rm equal to 638 MPa and 623 MPa. The ductility for the given draw is illustrated in Fig. 12, where is see that at reduction 31,79% the ductility decreased from 42% to 15%, and after recrystallization annealing to increase to 46%. On Figure 13 are Mechanical properties of the fourth sequence at one pass Rm = 527 MPa and Rp0.2 = 405MPa. The ductility at fourth sequence of the value of 46% dropped to 11% and subsequently rises after annealing at 46%. In the last five Sequence the reduction of 28.57% Finale mechanical properties were Rm = 593 MPa Rp0.2 = 579 MPa Elongation, and the final ductility was 13%. After the last sequence has been carried out final annealing.

6 MACROSCOPIC DEFORMATION

According to the chapter “Technology”, the plug drawing technology (1st and 2nd sequence) and the die drawing technology (3rd, 4th, 5th sequence) was considered, respectively.

The components of the strain tensor in the tube during the drawing process act in mutually perpendicular directions (see Fig. 17 and 18). During deformation, the tube cross-section changes, the wall thickness could change and all this is linked to the strains in outer and inner diameter of the tube – the hoop (tangential) strain φ1 and the radial strain φ2. From Tab. 3 it follows that the most significant strain in during 1st and 2nd drawing sequence is the axial strain φ3. On the other hand, the hoop strain φ1 takes the lead during 3rd, 4th and 5th drawing sequence and is related to the change of the tube perimeter before and after deformation (additional index denoting the outer perimeter V, the mean perimeter M and the inner perimeter S). The radial strain φ2 refers to the wall thickness before and after deformation and the axial strain φ3 refers to the tube length before and after deformation, respectively.

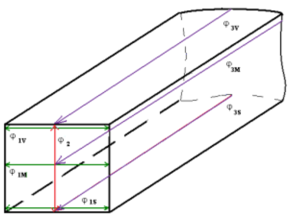

Figure 17. Scheme of deformation in a particular element.

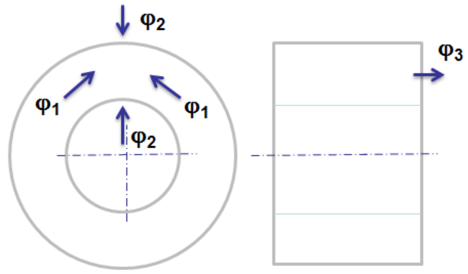

Figure 18. Scheme of deformations in the tube drawing .

All strains mentioned here are considered as true (logarithmic) strains that can be obtained as follows.

$$\varphi = \int_{L_0}^{L_1} \frac{dL}{L} = \ln \frac{L}{L_0} \qquad (2)$$

where L0 is the initial length (zero deformation state) and L is the final length.

According to the mighty law of forming, the sum of all principal strains must equal zero, i.e. φ1 + φ2 + φ3 = 0;

Table 3. Tube parameters in particular drawing seuence with the values of the deformation after individual passes.

	O.D. ∅ [mm]	M.D. ∅ [mm]	I.D. ∅ [mm]	W.T. [mm]	φ_{1V}	φ_{1M}	φ_{1S}	φ_2	φ_3	$\varphi_{1M}+\varphi_2+\varphi_3=0$
Seq/ Pass	31.8	30.5	26.6	2.6						
1/1	28	27	24	2	-0.13	-0.12	-0.1	-0.26	0.35	-0.03
1/2	25	24.25	22	1,5	-0.11	-0.11	-0.09	-0.29	0.37	-0.02
2/1	22	21.37	19.5	1.25	-0.13	-0.13	-0.12	-0.18	0.3	-0.01
2/2	18	17.55	16.2	0.9	-0.2	-0.2	-0.19	-0.33	0.51	-0.01
1/1	12	11.52	10.1	0.95	-0.41	-0.42	-0.47	0.05	0.38	0.01
1/1	8	7.5	6	1	-0.41	-0.43	-0.52	0.05	0.4	0.02
1/1	6	5.5	4	1	-0.29	-0.31	-0.41	0	0.33	0.02

Considering the drawing technology used (5 sequences with 7 drawing passes, see Table 2), great attention was also paid to the macroscopic surface quality. During drawing, no serious problems occurred. The 1st and the 2nd drawing sequence considered two passes per sequence. Due to the plug drawing technology used, the radial strain φ2 was significant, reaching values from

-0.18 to -0.33. In following drawing sequences, considering only one die drawing pass per sequence, the radial strain φ2 went from 0.00 up to 0.05. This reflects the fact that for die drawing technology, the wall thickness can actually increase a little bit, for there is no inner tool to hinder this phenomenon.

The precision tubes obtained can now be used in subsequent hydroforming process, producing vital parts especially for automotive industry [4].

7 CONCLUSION

In this paper, the main goal was to analyse mechanical properties and macroscopic deformation of precision seamless tubes during cold drawing according to the company's technological standards. In the experiment described here, we used two different principles of tube drawing technology, namely the die drawing and the plug drawing technology. The technological parameters were chosen in order to make the drawing process faster, cheaper, and simpler (i.e. optimized). Naturally, these parameters must strictly follow the ISO production quality standards. Either die or plug drawing, both principles have an influence on subsequent macroscopic strain analysis regarding volumetric invariance. When choosing a particular technology, the technologist must keep an eye on the mechanical and microstructural properties of the tubes before and after drawing, which is nothing just the goal of our research efforts so far. The next step evaluation experiment is macroscopic analysis of modifications of formed experiment material in particular draws and microscopic analysis for determination of the grain orientation grade with a simplified method and stereology.

8 CONCLUDING REMARKS

This s paper shows intermediate results from Research Project 3/2014/ŽPVVC „TUMIFORM – Optimization of precision tube drawing technology considering dislocation theory, microstructure, and plasticity limit“, currently being solved at ŽP Research and Development Centre in Podbrezová, Slovakia.

9 ACKNOWLEDGEMENTS

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11 NOTATION

(M.D. – mean diameter, O.D. – outer diameter, I.D. – inner diameter, W.T.– wall thickness, L – lenght tube, φ_1 – the hoop (tangential) strain and additional index denoting the outer perimeter V, the mean perimeter M and the inner perimeter S, φ_2 – the radial strain, φ_3 – the axial strain)