Reduction of Tubes Diameter by the Die and Mandrel in Simulation Software

Dušan Šuťák, Michal Hatala, Michaela Dilýová,
František Botko, Robert Poklemba

Technical University of Košice,Faculty of Manufacturing Technologies with a seat in Prešov, Department of Manufacturing Technologies, Bayerova 1, 080 01 Prešov, Slovak Republic

***Abstract* – The paper deals with the area of problems and solutions of cold drawing of a tube. This process is simulated with the help of Deform 3D software. The introduction includes solvability of the current state of affairs. The chapter material and methods consist of characteristics of the current state of production, preparation of pipes before drawing and design of the used material. The following chapter describes the tools that are commonly used during the drawing process. The results section shows the final simulation of deformation tube and the resulting analysis. The conclusion briefly characterizes the final objective of the contribution, the usability of these tubes and the overall application in various sectors.**

***Keywords* – reducing, simulation, analysis, mandrel, die, tube, pipe.**

1. Introduction

Rolling technology has already made its mark on tube and pipe production as early as the mid-19th century. Initially, rolled strips of sheet metal were formed into a circular cross-section where they were joined together by welding. By the end of the 19th century, when various processes became available for the production of seamless tubes and pipes, production volumes rapidly increased over a relatively short period. The company, founded in 1961 in the fields of western Siberia, developing new technologies used for the production of pipes of small and large diameters. By placing a high emphasis in the area of tubes and pipes leading to chemical and physico-chemical area. [1]

Tandem skew rolling (TSR) is a new metal forming technique for the production of seamless steel tubes. It is a process of combining multiple formations into one step. These simulations can be performed with the aid of FEM software, to refine and display detailed analyzes. [2],[3] It is this method that showed the possibility and process for the production of seamless steel tubes, with a high emphasis on production quality. [4]

The term Mannesmann process is used in the drawing and rolling processes. The drawing and rolling methods are used for the production of seamless tubes. The first process used for pipe extension was the rolling process. The internal cavities arise from tensile stresses of the round bar (rotary extrusion process). [5]

Tools used for pulling pipes must meet the required properties. They are made with high wear resistance and high compressive strength. These are tools made by powder metallurgy. The right choice of tool material plays a very important role, where it is necessary to observe an important factor, namely wear resistance. To improve wear resistance, various coatings are used to extend the life of the cutting edges of the tools. When using a particular tool material, it is also necessary to determine the optimum coating. [6]

The finite element method (FEM) is used for the simulation part. This method is used to express stresses, deformations, thermal phenomena during the process etc. With the forces applied during tube forming and process deformations, deficiencies can be anticipated and avoided. [7] The resulting analysis is based on a mathematical expression of the model, which includes boundary conditions etc. By the help the FEM software, the temperature points of the forming tool can be found. [8], [12]

DOI: 10.18421/TEM91-52
https://dx.doi.org/10.18421/TEM91-52

Corresponding author: František Botko,
Technical University of Kosice, Faculty of Manufacturing, Technologies with a seat in Presov, Slovak Republic
Email: frantisek.botko@tuke.sk

Received: *19 December 2019.*
Revised: *07 February 2020.*
Accepted: *12 February 2020.*
Published: *28 February 2020.*

From the economic point of view, this direction also has a strong potential, where the use of simulation software helps predict the behavior of materials. That is why there will be less cost and saving time. [13]

2. Material and methods

Current state of production

The division of tubes is based on several aspects:

- method of production
- cross section shape
- area of application of tubes
- modification of tube ends

A steel tubes is a product which has the same circular or other hollow cross-section along its entire length and is open at both ends. Tubes are an important factor nowadays in the thermal, transport and construction industries.

In Slovakia, pipes and tubes are manufactured in Železiarne Podbrezová, a.s., where the main focus is on seamless pipes. They are produced by hot rolling and are subsequently reduced and cold drawn. Pipes produced by drawing have better mechanical properties, better surface and more accurate dimensions. Their cost is more expensive than in the case of rolled pipes, mainly because more work and energy is needed to produce them. [9]

Preparation of pipes before drawing

The preparation of the pipes prior to the drawing process includes narrowing of the end of the oven, pickling and surface treatment. A hollow spike must be formed at the end of the trolley to hold the pipe. The length of the tip depends on the diameter of the pipe and ranges between 100-200 mm. For further phosphating, it is necessary that the pointed end remains open. [10]

Pickling in an acid of the tube before drawing removes residues of metal fragments on the external and internal surfaces of pipes. Also, this achieves a reduction of friction resistance, preventing seizing pipes in the drawing process. In more than 90% of cases, inorganic acids (sulfuric acid and hydrochloric acid) are used for pickling. [11]

The phosphate surface treatment of the pipe is particularly suitable for carbon or low-alloy steels. This creates a phosphate coating on the pipe surface, which together with the grease layer prevents direct contact of the pipe with the pulling tool. The tubes are in the phosphating bath at 60 ° C immersed for as long as the total does not pass through the tip tube while the removal of air. Phosphate zinc is in response located on the steel surface, creating a layer of preservative. Alloy steel is treated before pulling coated by plastically metal on their surface. For this operation, the use of copper or lead. [10]

Material selection

Steel S235JR (1.0038) EN10025-2

Weldable unalloyed structural steel. Suitable for welding by all commonly used welding methods. This steel S235JR is easy to process, easy to mold and ideal for all welding methods. Material under number 1.0038, is the most commonly used structural steel in the metalworking industry.

This class S235 is not intended for heat treatment because the forces and strength parameters are precisely defined. The material is not resistant to corrosion, therefore it is necessary to protect it by surface treatment. The process for refinishing is called application hot-dip galvanizing or organic coating. [14]

Chemical composition

Table. 1 Chemical composition material S235JR [14]

Weldability	C%	Mn %	P%	S%	Cu %	N%
Pcm 0.25_{max}	0.17	1.4	0.035	0.035	0.55	0.0120

Mechanical properties

Table. 2 Mechanical properties S235JR [14]

Dimension [mm]	Yield strength min [MPa]	Tensile strength [MPa]	Elongation A_5 [%]	Impact (ISO-V) $strength_{min}$
< 16	235*	360-510	26	20°C 27J (long)
16.1 < 40	225*	360-510	26	20°C 27J (long)
40.1 < 63	215*	360-510	25	20°C 27J (long)
63.1 < 100	215*	360-510	24	20°C 27J (long)
100.1 < 150	195*	350-500	22	20°C 27J (long)
150.1 < 200	185*	340-490	21	20°C 27J (long)

Other properties (typical values)

Table. 3 Other properties S235JR [14]

Youngs module (GPa)	210
Shear module (GPa)	80
Density (kg/m^3)	7800
Specific heat capacity 50/100°C (J/kg°K)	460-480
Thermal conductivity Ambient temperature (W/m°K)	40-45
Electrical resistivity Ambient temperature (μΩm)	0.20-0.25

3. Conclusion

Tools used for pulling

For the manufacture of precision cold drawn tubes, mandrels and dies are used.

Mandrels – determine the dimension of the inner diameter.

They are made of steel alloys, followed by hardened or chromed. The surface of the mandrels is polished to the level of mirror shine.

From the shape point of view we divide the mandrel into:

- Cylindrical shape – mandrels of larger diameters are fitted to the tow bar, which is secured with a nut (Fig.1A). The shape of the mandrels of smaller diameters passes from the cylindrical part to the threaded shank, which is fastened to the tow bar (Fig.1B). [11]

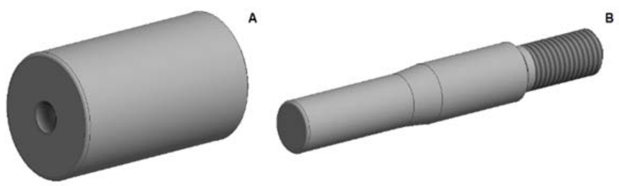

Figure 1. Cylindrical mandrels used for pulling pipes

- Conical shape – this type is used for a wider range of drawn rod diameters. In the central part of the mandrel, a narrow cylindrical plate divides the two conical surfaces of the mandrel and determines the dimension of the inner diameter of the tubes during the drawing itself (Fig.2.). These mandrels are mounted on the tow bar and secured with a lock nut.[11]

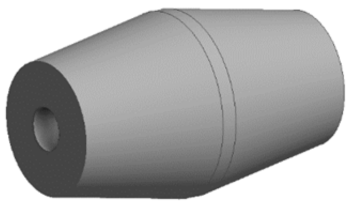

Figure 2. Conical mandrel used for pulling pipes

Dies – determine the outside diameter dimension
For their production are used hardened and tempered tool steel, but largely are used sintered carbides. The demands on the quality of the mandrel surface are very high, as the surface roughness is set at **Ra = 0.2 – 0.4 µm**.

For cold drawing of tubes, conical dies with a cylindrical smoothing zone are used. The shape of the die is adapted to the method of drawing, as well as the shape of the mandrel (Fig.3.). [11]

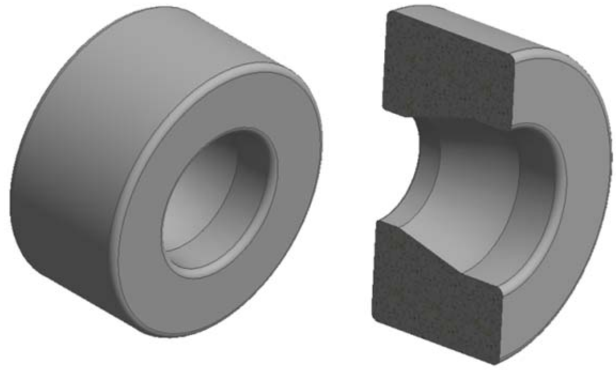

Figure 3. 3D view of the die and the die in section

Principle of operation

The principle of the cold drawing process lies precisely in the operation where the pipe is reduced from the basic diameter to the desired diameter. The pipe is pulled by the tapered end (tipping) through the die. The die does not make any movement, because it is stored in the drawing stand. The mandrel is inserted in the pipe and secured to the tow bar. Its task is to change the inner diameter of the pipe to the final one. During the process of pulling there is a change of pipe diameter outer and inner walls, while changing the length of the pipe.

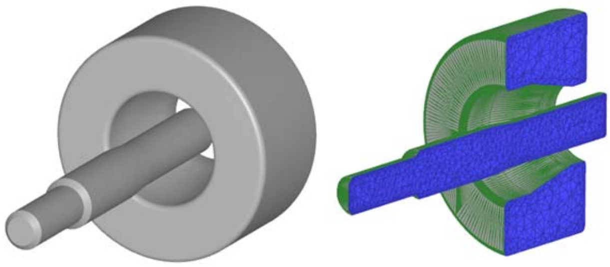

Figure 4. 3D assembly (mandrel and dies)

Software simulation

Simulation analysis is carried out with the help of software called Deform 3D. It is a simulation system that is designed to analyze three-dimensional (3D) processes of metal, plastic, etc. Helps predict the behavior of materials under load or deformed. Deform 3D offers the possibility of simulating hot forming, cold forming, rolling, milling, turning and drawing.

With the help of simulation it is possible to see and predict the behavior of the material at different loads. In Figure 5. we can see the course of the simulation, which reduces the diameter of the pipe.

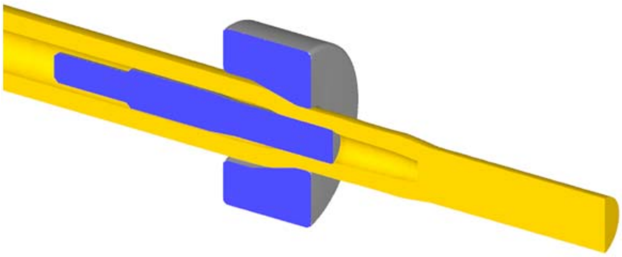

Figure 5. 3D view of the drawing process in section

Table 4. Dimensional values of tested parts

Mandrel	
Diameter [mm]	16
Length of the forming groove [mm]	43
Length of the whole tool [mm]	126
Die	
Input diameter [mm]	40
Output diameter [mm]	28.6
Bevel from the axis [°]	16
Drawn tube	
Diameter [mm] (external/internal)	36/19.5
Length [mm]	420

Table 4. contains the specified dimensions of the tested models in the simulation. This is a test consisting of a mandrel die and drawing tubes. These are the values that give the dimensional part of the parts. This is required for entering and determining for subsequent simulation in the Deform 3D software program.

4. Results and discussion

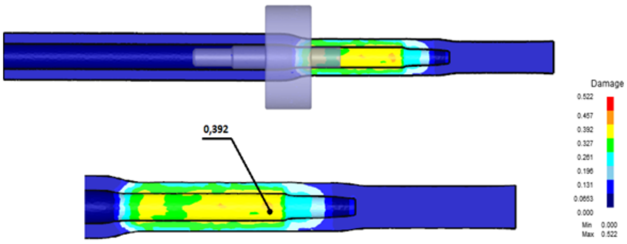

Figure 6. Simulation of the deformation tube

In Figure 6. is presented a simulation of the deformation tube. The upper part shows the deformation of the die used and the forming mandrel. It is a representation of the largest deformation region during the drawing operation. The lower figure recorded the largest amount of deformation and 0.392. From this figure we can see that the greatest deformation was in the area of reducing the inner diameter of the pipe.

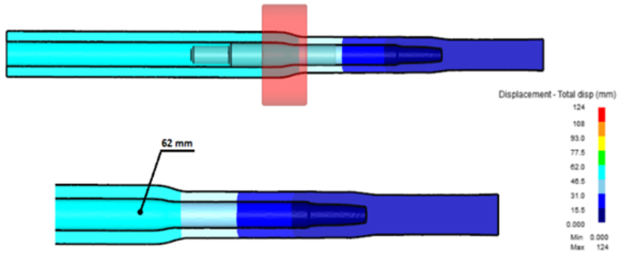

Figure 7. 3D simulation of the resulting total extrusion analysis

Figure 7. shows the resulting overall extrusion analysis. During simulation of reducing the outside and inside diameter of the tube travelled of 110 mm, the length was extended to 62 mm. This length at the end always has a greater elongation. The value of the total extrusion depends on entering the initial diameter of the pipes and the actual length before the pulling operation, up to the resulting one. Of course, the length of the pipe must also be taken into account so as not to tear the pipe due to its length.

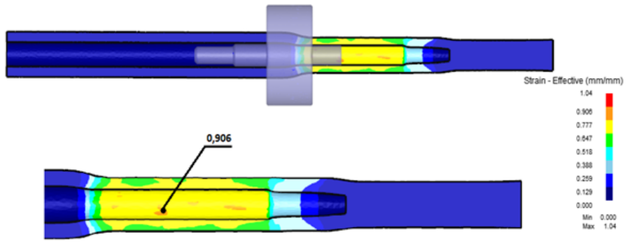

Figure 8. 3D simulation of stress effective

Figure 8. shows a simulation of strain effective. The upper part shows the simulation with the used die and the forming mandrel. In this simulation, the stress value from the initial zero climbed to 0.906. This value is not altered during the whole simulation respectively stabilized at a single value.

The maximum strain value is indicated in more detail. In this view, it can be seen that the greatest stress has been recorded in the area of reducing the internal diameter.

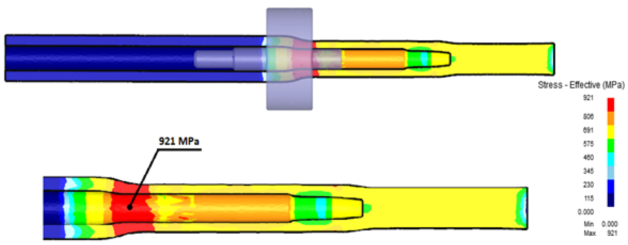

Figure 9. 3D simulation of mechanical stress effective

Figure 9. shows the course of the simulation of the mechanical stress effective. As in the previous case, here is a simulation using a die and a forming mandrel. In the more detailed illustration of the figure, the highest measured value of 921 MPa is indicated. This value does not increase but is stable. Only the place of stress on the pipe is changed, always at the place where the outer and inner diameters are reduced. Right there occurs the biggest area of deformation which results in precisely the greatest efficiency of mechanical stress.

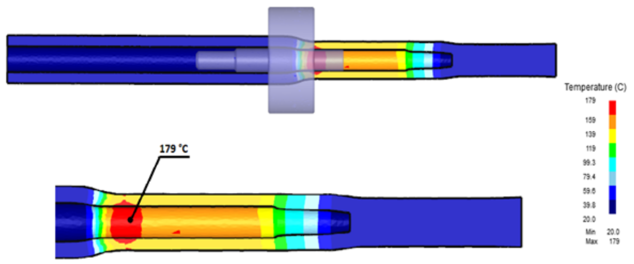

Figure 10. 3D simulation of temperature analysis of test tube

Figure 10. shows a simulation of the temperature analysis of the test tube. During the test, the initial temperature was set to 20 ° C, which is entered as the normal operating temperature. During the simulation, this temperature has risen to a maximum value of 179 ° C. At the same time, this maximum temperature has stabilized and the value has not changed during the entire drawing process. As in the previous case, the highest measured value was always in a place where there was a reduced external and internal diameter. Precisely because of higher temperatures, it is necessary to use coatings, whose role is to maintain an optimum temperature of pipes for drawing, but also transitory way of drawing.

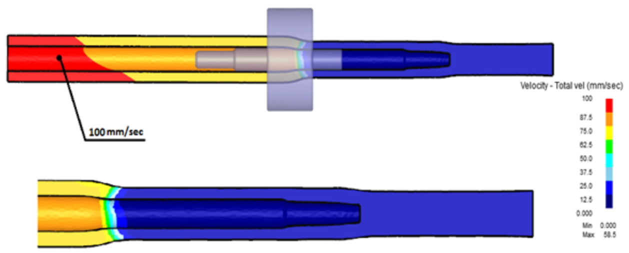

Figure 11. 3D simulation of total speed during oven extension

Figure 11. shows a simulation of the overall speed during the elongation of the pipe. This is a value where, during drawing, the pipe diameter is reduced while the pipe lengthens. A maximum value of 100 mm/sec was measured during the pull simulation. This value was constant throughout the simulations.

Table 5. is the result table. It consists of the measured values before simulation (initial value) and after simulation (maximum value). Initial values were entered before the simulation was run. The maximum measured values were still in the interface area which still met the requirements for the drawn tube material to be tested. It was made of steel S235JR (1.0038) EN 10025-2.

Table 5. Initial and maximum measured values in simulation

	Minimal	**Maximum**
Deformation of the tube – Damage	0	0.392
Displacement – Total displacement (mm)	0	62 (at length 110 mm)
Strain – Effective (mm/mm)	0	0.906
Stress – Effective (MPa)	0	921
Temperature (°C)	20	179
Velocity – total velocity (mm/sec)	0	100

5. Conclusion

The paper aimed to tackle tube drawing. The cold drawing process is a process that involves changing the diameter, changing the wall thickness, changing the length, changing the shape and dimensions of the cross-section, refining, reducing the dimensional and shape deviations, changing the mechanical properties and improving the surface quality. The advantages of this pulling of pipes include simplicity, high production, low-cost production equipment and the possibility of pulling even the more difficult form of metals.

These tubes can be used in several areas. They may be tubes for the manufacture of hydraulic and pneumatic cylinders. In the case of tubes for pressurized hydraulic and pneumatic circuits, these tubes are mainly used for pressure distribution of media in hydraulic and pneumatic equipment. Drawn tubes also have a place in the automotive industry, such as tubes for injection device for diesel engines.

Seamless steel tubes can be supplied as different types of tubular blanks according to the needs and requirements of customers. Further, cold drawn tubes are predominantly processed but, if desired, hot rolled tubes can also be supplied in the form of various blanks. A significant advantage of precision tubes over hot rolled tubes is high dimensional accuracy, good surface quality, guaranteed mechanical and technological properties. For these reasons, the precision tubes widely used in the engineering industry, in the manufacture of transport and other equipment. Heat exchanger tubes for elevated temperatures are the kind of precision tubes used in heat exchange equipment where energy is transferred from one medium to another. Heat exchangers are used in the energy, chemical industry, heating buildings, domestic water heating and the like.

After the resulting simulation software Deform 3D, we can see the final analysis, which highlighted the impacts during stretching (drawing) tube through the die. This simulation helps us to predict the behavior of the tube during drawing, thanks to which we can avoid mistakes and shortcomings. In the resulting simulations, it is possible to see the deformation change, the resulting total extrusion analysis, the strain effective, the mechanical effective stress, the temperature analysis and the total speed during oven extension.

The main contribution of this paper is deepening and expanding knowledge in the field of the use of tubes in heat exchangers. Another benefit is part of the contribution specifically for science in the tube drawing cold. Also, in the field of Deform 3D software, using the solution of specific materials used in simulations.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0696. Paper was supported by grant VEGA 1/0682/17. "Paper is the result of the Project implementation: Automation and robotization for 21st century manufacturing processes, ITMS: 313011T566, supported by the Operational Programme Research and Innovation funded by the ERDF."

References

[1]. Blinov, Y. I. (2001). Russian Tube and Pipe Institute on Boundary of Centuries. *STAL'*, (9), 97-100.

[2]. Wang, F. J., & Shuang, Y. H. (2016). Tandem skew rolling process for compact producing seamless steel tubes. *Iron Steel*, *21*, 44-48.

[3]. Yan, Z., Zhuang, G., & Sun, Q. (2010). *New manufacturing technique on seamless tube rolling*. Paper presented at the Proceedings of the 10th International Conference on Steel Rolling.

[4]. Wang, F. J., Shuang, Y. H., Hu, J. H., Wang, Q. H., & Sun, J. C. (2014). Explorative study of tandem skew rolling process for producing seamless steel tubes. *Journal of materials processing technology*, *214*(8), 1597-1604.

[5]. Kümmerling, R., & Kraemer, K. (2015). Pipe Manufacture—Seamless Tube and Pipe. *Oil and Gas Pipelines*, 211-222. Doi: 10.1002/9781119019213.ch15 .

[6]. Dorogan', T. E., & Kolikov, A. P. (2003). Service life of tube tools. *Stal',* (12), 55-57.

[7]. Azizoğlu, Y., Gärdsback, M., Sjöberg, B., & Lindgren, L. E. (2016). Finite element modeling of tube deformation during cold pilgering. In *MATEC Web of Conferences* (Vol. 80, p. 15004). EDP Sciences.

[8]. Prince, J. C., Marono, R., & Leon, F. (2003). Thermomechanical analysis of a piercing mandrel for the production of seamless steel tubes. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *217*(4), 337-344.

[9]. Donnet, C., & Erdemir, A. (2004). Historical developments and new trends in tribological and solid lubricant coatings. *Surface and coatings technology*, *180*, 76-84.

[10]. Rudolf, B., & Kopecký, M. (1979). *Tvářecí stroje: Základy výpočtů a konstrukce: Vysokoškol. učebnice*. SNTL.

[11]. Bača, J., & Bílik, J. (2000). *Technológia tvárnenia*. Slovenská technická univerzita.

[12]. KumAR, R., ChAttopAdhyAyA, S., Hloch, S., Krolczyk, G., & Legutko, S. (2016). Wear characteristics and defects analysis of friction stir welded joint of aluminium alloy 6061-T6. *Eksploatacja i niezawodność*, *18*.

[13]. Schindlerová, V., Šajdlerová, I., & Lehocká, D. (2018). Dynamic simulation for optimisation solution of manufacturing processes. In *MATEC Web of Conferences* (Vol. 244, p. 01010). EDP Sciences.

[14]. Agarwal, V. (2010). Steel Handbook–A Guide to World Equivalent Steel Grades. *Vishwas Techno-Publications, Mumbai*, 6-2.