NUMERICAL SIMULATION OF EXTRUSION ELBOWS

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Abstract
The article is focused on the study of welding elbows extrusion throught numerical simulations. The steel grade 11353 was used as a experimental material. The numerical simulations were carried out to optimize the technological scrap. The welded elbows 90° with external diameter and wall thickness 88,9 x 3,2 mm were processed using software product Deform 3D and were compared with physical simulations. Numerical and physical simulation showed high conformity. Moreover, the process of logaritmic and proportional deformation was also investigated by physical simulations. Finally, it was found, shortening of the expansion and calibration mandrel end led to the decreasing of technological scrap

Keywords: extrusion, mandrel end, welded elbows, fibers

Introduction

In the present time, numerical and mathematical simulation represent the right choice for determination of various forming processe, including all materials selection base. In order to understand various processes like as the workpiece, die design, the friction conditions, temperature behaviour etc.; it is essential to combine experimental research with a theoretical analysis of inhomogeneous deformation behaviour in the workpiece/specimen during the process [1-4]. Seamless welded elbows are used as a part of various piping systems, for the purpose of use as elbows for general application, elbows for pressure pipes (high temperature, low temperature) elbows for gas and water. Seamless welded elbows are made seamless steel tubes by hot forming using the mandrel [5,6]. Rolled tubes are divided into cutting pipe semi-product required length by the size of the elbow. Cutting pipe semi-product is slipped on mandrel bar. Using the compression stool head cutting pipe semi-product is moved a speed 0.8 - 1.1 m/min. Temperature in the range 800 – 850 °C through the mandrel end. Tool shape and forming technology would be providing the same wall thickness around the perimeter and along the elbow, which is identical with the thickness of input pipe. This method is also called "The Hamburg" [7]. During elbow extrusion the initial semi-product length is being reduced while the diameter is being extended. The extruded 180° welded elbow is divided into two 90° by cutting. Subsequently, are cut off excess ends. The final operations are chip division and treatment. The ends of the elbows are calibrated for cold and subsequently they are squared. The achievement of minimal technological waste as well as reduction of process during elbows manufacturing have been the main objective. The authors [8-10] described material flow during bending operation as follows: fibre on external side elbow radius is without deformation, while fibres in the direct to inside radius were account by the increase of compressive and tensile strains. The radial material flows from inside to outside radius and at the same time axial material compression in inside radius line were observed. Material flow during elbow extrusion process is mainly depends on process parameters an extrusion temperature and rate, steel workability, contact friction and shape and geometry of mandrel end [11]. The mandrel end geometry has to provide uniform material flow by wall thickness through cross section and elbow length stabilization [12, 13]. According to the geometry of mandrel end (**Fig.1**), is obvious that mandrel end is dividend to by parts namely [14]: I – guide segment, II – drift segment, III – deformation segment, IV – calibration segment. The I-segment is needed to centric loading of cutting pipe semi-product introduction on equipment, II-segment allows continuous cutting drifting of pipe semi-product, III-segment is zone for intensive plastic deformation, IV-segment is needed for shape calibration of extruded elbow. External curve segments II and III is created by circle with radius of bending elbow as is given in equation (1). The segment III includes curved conus which provide the gradual spreading and pipe semi-product incurvation. Therefore, the plastic deformation causes radial size expansion as well as the axial size of pipe semi product reduction [15]. Segment IV curved roller ($D_{Mandrel}$) with equal diameter as internal diameter of final elbow by equation (2).

$$R_A = R + D_{Mandrel}/2 \tag{1}$$

Where:
R - bending elbow radius [mm]
$D_{Mandrel}$ -diameter of mandrel end [mm]

$$D_{Mandrel} = D_{Elbow} - 2.s \tag{2}$$

Where:
D_{Elbow} -diameter of elbow [mm]
s - wall thickness [mm]

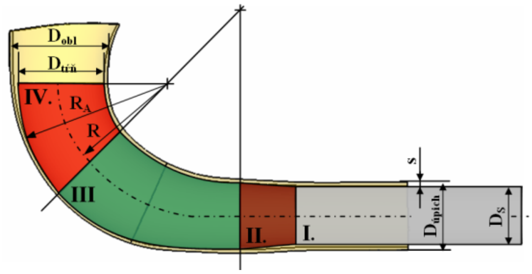

Fig.1 Basic geometry of mandrel end

Material and experimental methods

Physical simulations were performed at the working conditions. For physical simulation semi material with steel grade 11 353 with chemical composition given in **Table 1** was used for physical simulation.

Table 1 Chemical composition of the material with steel grade 11 353

Steel grade	C	Mn	Si	P_{max}	S_{max}	Cr	Ni	Cu
11 353	0,1	0,45	0,3	0,025	0,025	0,15	0,25	0,25

The rectangular network with l_0x l_0 = 20x20mm was mechanically given to semi-product with initial parameters D x t x L = 63.5 x 3.2 x 290 mm (D - outer diameter, t - wall thickness, L -

length semi product) was applied, according to the **Fig.2**. After semi product pressing through mandrel end, the individual parameters of elements on 90° welded elbow were measured (**Fig.3**). The physical simulation conditions were: heating temperature 850 °C , mandrel end temperature 780 ºC, ambient temperature 20 °C, speed of semi product movement 0.8 ÷ 1.1 m / min, method of lubrication (semi product - tool) graphite mixture. The program Deform 3D (based on FEM analysis) was used to as suitable tool for real work conditions simulations [16, 17]. The geometric task for numerical simulations composed following objects: mandrel end, three upon yourself continuation cutting pipe semi-products and hydraulic press panel. The cutting pipe semi-product was defined as rigid – plastic object. The semi product parameter was the same as during physical simulation. The process of bending elbows was simulated in the following temperature conditions: $T_{semi\ product}$ = 850 °C, $T_{mandrel\ end}$ = 780 °C. Semi product heating was defined as the induction. The friction conditions between the mandrel and semi product were defined in according with Shear friction model with f = 0.1 [18]. This friction value corresponds to friction conditions during the hot forming with lubrication. Semi product geometry was described using finite elemental net 60 000 elements. Mandrel end was defined as a ideal rigid and into the Deform 3D has been imported by planary network. Hydraulic press panel (compression head) was defined as a solid object moving with constant speed of 1 m / min. Scheme model extrusion elbows is shown in **Fig.4**.

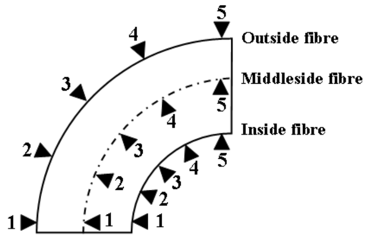

Fig.2 Scheme of measurement for assessing the intensity of deformation

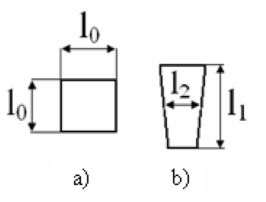

Fig.3 Drawing element: a) before deformation, b) after deformation

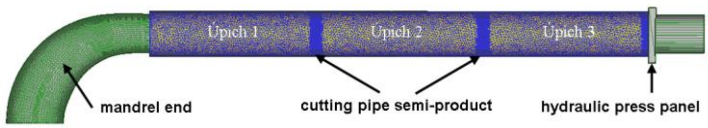

Fig.4 Diagram compiled simulation program Deform 3D

Logarithmic and relative deformations were calculated from measured parameters of network individual elements at measurement point. Linear logarithmic strain was calculated according to equation [1]:

$$\varphi_1 = \ln\left(\frac{l_1}{l_0}\right) [-] \tag{3}$$

$$\varphi_2 = \ln\left(\frac{l_2}{l_0}\right) [-] \tag{4}$$

Where:
φ_1 - linear logarithmic strain across the length [-]
φ_2 - linear logarithmic deformation across the width [-]
l_0 - element length before deformation [mm]
l_1- length measured by the network element after deformation [mm]
l_2 - width measured by the network element after deformation [mm]
To obtain the values of strain intensity is necessary to calculate the relationship under strain [1]. For the purpose values of relative strain intensity obtaining is needed following equation:

$$\varepsilon_n = e^{\varphi} - 1 \tag{5}$$

Where:
ε - Relative deformation [-]
The deformation intensity in different locations is given by the general equation [1]:

$$\varepsilon_i = \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2}\ [-] \tag{6}$$

ε_1, ε_2, ε_3 - components of the relative deformation in different directions
ε_3 - neglected because the variation in wall thickness did not change at warp

Results and discussion

The **Fig.5** and **Fig.6** show logarithmic deformation of elements parameters at measured point on the individual fibres. The greatest deformation was observed in the inside fibre. The element length on the individual fibres was increased doubly and the width was reduced double. Axial tensile deformation reached a mean value $\varphi_{1str} \approx 0.75$. It was caused by raising compressive stress in inside fibre of hot welded elbow. There were observed the largest plastic deformation of elements through the length. The greatest tensile stress was achieved in this fibre. Compressive deformation reached $\varphi_{2str} \approx -0.76$. In the middle fibre of the welded elbow were recorded as minor distortions in the inside fibre. The element length was slightly widened and the width was slightly reduced, because the tensile and compressive stress has not such influence in the middle fibre. In the axial direction was recorded value of the tensile strain $\varphi_{1str} \approx 0.29$. Compressive deformation reached $\varphi_{2str} \approx -0.2$. Deformation on the outer fibre was the smallest recorded. Element parameters were changed only minimally. Tensile deformation reached $\varphi_{1str} \approx 0.05$. Compressive deformation reached $\varphi_{2str} \approx -0.05$. Deformation intensity in the every curve fibre is shown in **Fig.7**. The greatest value of deformation intensity was recorded in the inside fibre, where the network element is most deformed. The deformation intensity in the inside fibre was being recorded in the range $\varepsilon_i = <0.92; 0.99>$. The middle fibre of the welded elbow was observed deformation intensity $\varepsilon_i = <0.29, 0.32>$. Minimal deformation intensity was calculated on the outer fibre, where the network elements were changed minimally, the deformation intensity was in the range $\varepsilon_i =<0.04, 0.07>$.

The **Fig.8** is showed geometric comparison between numerical simulations and physical simulation of extrusion steel elbows. The value exceed given from physical simulation was 15 mm. Although program Deform 3D revealed 14 mm, what implies great correlation, between physical and numerical simulations. The difference in values is within ± 1mm. The results of physical simulations on non-optimized geometry of mandrel end revealed to high technology scrap presence.

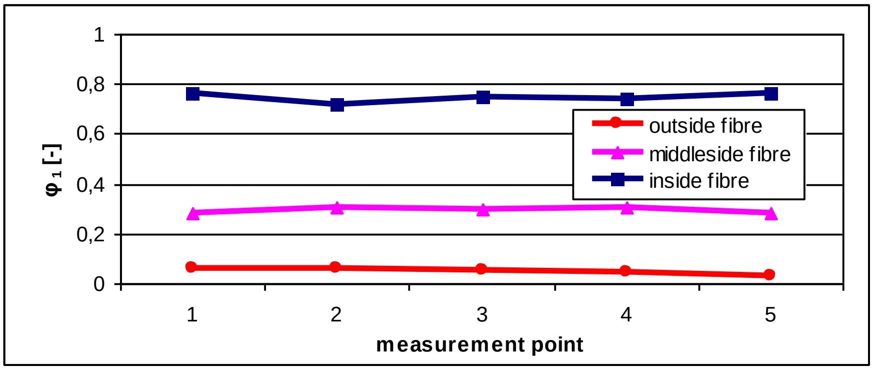

Fig.5 Graphic representation of linear logarithmic deformation lengths for the elements of thread elbow

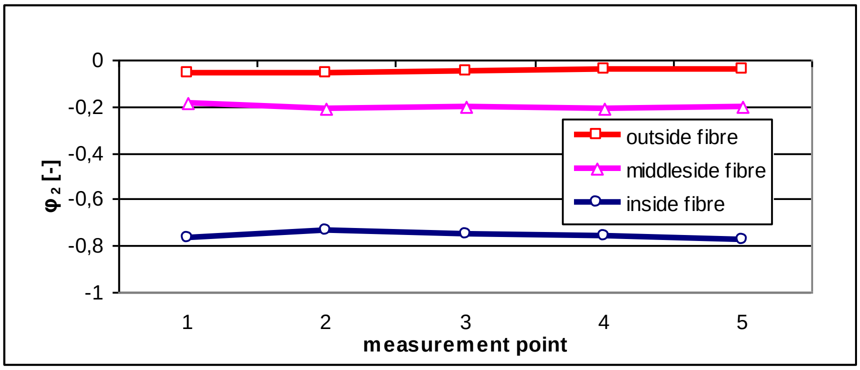

Fig.6 Graphic representation of linear logarithmic deformations of the widths of the elements of thread welded

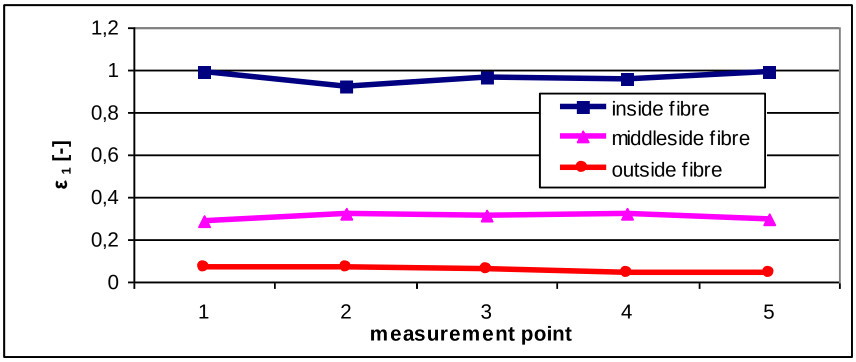

Fig.7 Graphic display of the intensity of strain in the fibres of the elbow

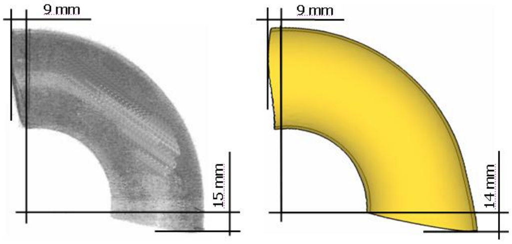

Fig.8 Geometric comparison: a) deviation in the perpendicularity of physical simulation, b) deviation from perpendicularity of the numerical simulation program Deform 3D

The numerical simulation from software Deform 3D purpose was to consider the front and back technological scrap quantity, dependence on the changing geometry of mandrel end. Optimized mandrel end shortened expandable part and shortened the calibration part of the original 45° (**Fig.9a**) at 30° (**Fig.9b**) when it was adapted to the geometry of the forming section. After numerical simulations, new model seemed to be more efficient because the excess value was up to 5 mm (**Fig.10**), which results in significant technological scrap reduction in comparison with the physical simulation.

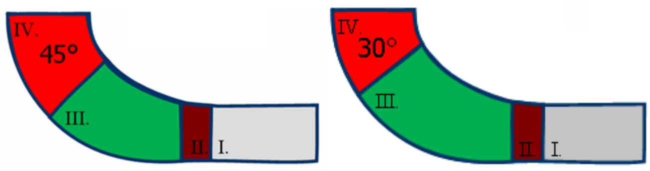

Fig.9 The models of mandrel endings: a) original model b) optimized model

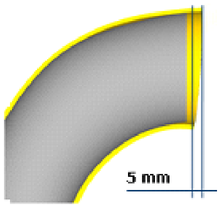

Fig.10 The technological scrap quantity

Using the new optimized shape mandrel end provides direct production of steel 90° elbows with lower technological scrap quantity. Consequently, the reduction of production time by two technological steps remaining (cutting 180° elbows on 90°) end calibration results energy saving.

Conclusions

Numerical simulation and technological experiment results are possible summarize as follows:

- according greatest strain values were observed in the internal fibre. Axial tensile strain reached a mean value $\varphi_{1str} \approx 0.75$. Compressive strain reached $\varphi_{2str} \approx -0.76$,
- the smallest strain value was noted in the external fibre was the smallest recorded.

Element parameters were changed only minimally. Tensile deformation reached $\varphi_{1str} \approx 0.05$. Compressive deformation reached $\varphi_{2str} \approx - 0.05$,

- the largest value of strain intensity was recorded in the inside fibre, where the network element is most deformed. Namely: in the length direction, it was two times reduction. In the width direction, it was two times elongation,
- mandrel end model with a reduced calibration and expandable part (from 45° to 30°) appears to be most effective in terms of technological scrap. The exceed between the outer and inner fibre was established $\Delta_{overhang} = 5$ mm,
- model the new terminal elbows provides the direct production of steel 90 ° elbows, what results in reduction of working process steps.

References

[1] M. Kvačkaj, T. Kvačkaj, A. Kováčová, R. Kočiško, J. Bacsó: Acta Metallurgica Slovaca, Vol. 16, 2010, No. 2, p. 84-90.
[2] J. Tiža, T. Kvačkaj, M. Lupták: Acta Metallurgica Slovaca, Vol 15, 2009, No. 4, p. 241-247.
[3] J. Bidulská, T. Kvačkaj, R. Bidulský, M. Actis Grande: High Temperature Materials and Processes, Vol. 28, 2009, No. 5, p. 315-321.
[4] R. Bidulský, J. Bidulská, M. Actis Grande: High Temperature Materials and Processes, Vol. 28, 2009, No. 5, p. 337-342.
[5] T. Kvačkaj: Hutnické listy, vol. 1, 2010, No. 3, p. 31-36.
[6] M. Žídek: : Metallurgical steels of hot forming, VŠB Ostrava, 1982 (in Czech).
[7] A. Vítek: Pipe bending, SNTL Praha 1966 (in Czech).
[8] E. W. Mielnik: Metalworking science and engineering, McGram-Hill, 1991 (in Poland).
[9] T. Kvačkaj: Acta Metallurgica Slovaca, Vol. 8, 2002, No. 2, p.160-164.
[10] J. Veselková: Acta Metallurgica Slovaca, Vol. 2, 1996, No. 10, p. 112-116.
[11] M. Kollerová: Rolling, Alfa Bratislava, 1991 (in Slovak).
[12] E. Spišák: Mathematical modelling and simulation of technological process-drawing, TYPO Press, Košice 2000 (in Slovakia).
[13] K. Maár: Pressing and drawing, 1985 Bratislava (in Slovak).
[14] T. Kvačkaj: Acta Metallurgica Slovaca Conference, Vol. 1, 2010, No. 3, p. 73-77.
[15] S. Gubkin: Outline theory of metal forming. Mašgiz, 1959 (in Russia).
[16] M. Zemko: Matematical Modeling of Steel Structure Evolution of Seamless Tubes Hot Rolling. In: 13. International Students Day of Metallurgy, Leoben, 2006, p. 102-113.
[17] M. Zemko: Acta Metallurgica Slovaca, Vol. 4 2005, No.4, p. 412-418.
[18] Manual Deform 3D, Version 6.1, User´s Manual, 2007.