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COMPARISON OF DIE GEOMETRY FOR COLD DRAWING OF MULTI-RIFLED STEEL TUBES

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Multi-rifled tubes, i.e. tubes with multiple inner grooving are used in heat exchangers and boilers, providing favourable heat transfer conditions due to turbulent flow of cooling medium. Therefore, strict requirements are placed on the geometry of inner rifling. In production of such tubes, cold drawing with free-to-rotate rifled plug is the final drawing operation to achieve required dimensions. A Finite Element Method (FEM) based numerical model of the process was prepared in order to optimize the geometry of the die. The results of numerical simulations for two different die geometries show the difference in material flow and corresponding drawing force. The final dimensions of the tubes after drawing were compared with the customer`s requirements and a good agreement was found.

Key words: steel tubes, cold drawing, die geometry, FEM, numerical simulation

INTRODUCTION

Multi-rifled tubes, i.e. tubes with multiple inner grooving are used in heat exchangers and boilers. Over the last few years, the effect of multi-rifled boiler tubes has been highly valued mainly in power generation at supercritical pressures in coal-fired power plants [1]. The production of multi-rifled tube is quite complicated. The smooth tube is turned into the multi-rifled one after the final cold drawing pass. The goal of manufacturers is to reduce production costs, tools loading, tool wear and to improve the tube quality.

Nowadays, the analysis of material flow during cold forming is frequently done using computer modelling and numerical simulation. These tools allows us to assess the stress-strain state in the material subjected to complex geometrical constraints, material models, and boundary conditions.

Using the simulation software DEFORM-3D we compared two different die geometries and assessed the simulation results with respect to the final geometry of the tube.

EXPERIMENTAL PROCEDURES

Simulation parameters and calculation settings in DEFORM-3D were exactly the same for all models considered. The input feedstock was defined as a plastic object, suitable for modelling of cold drawing process under certain conditions [2–5]. A 3D model of tube with ¼ symmetry was 70 mm long and described by 30 000 linear tetrahedrons (Figure 1). Smaller elements were placed on the inner tube surface where high intensity of plastic deformation takes place. After the drawing the number of elements increased 10-fold. This was necessary to ensure the strict dimensional requirements on inner grooving of the tube (ribs, grooves, rounded edges, etc.) This approach is very effective and less time consuming as it requires fewer elements to describe the lower-priority regions, placing finer elements to the higher-priority regions according to the meshing weights. The forming tools (die, plug, carriage) were considered rigid and wear-free objects. During drawing, the multi-rifled plug revolves around its own axis due to the helical shape of the grooves, determining the flow of the material. The Coulomb friction coefficient between the die and the tube and between the tube and the plug was estimated to be 0,04. In the simulations, two different die geometries, which differed in reduction and bearing zone were used (Figure 2). Final dimensions of multi-rifled tubes after simulated drawing were measured in cross and longitudinal sections as specified in Figure 3. The results are in Table 1.

In experimental drawing, a T12 steel tube of input feedstock dimensions Ø 36 x 8 mm into multi-rifled tube Ø 28,6 x 6,3 mm was drawn. The multi-rifled plug, which rotates around its own axis and thereby creates the grooving pattern on inner surface of the tube was used during drawing process. In this process, die geometry No. 2 was used. The drawing speed was 1,85 m/min. The experiment was conducted at the room temperature. The tube dimensions after drawing were measured by 3D scanner GOM ATOS II and the data obtained were processed in order to obtain a reverse-engineered CAD model of the tube [6].

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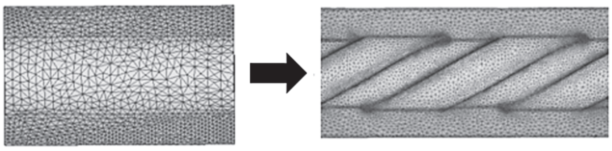

Figure 1 Mesh topology before (left) and after drawing (right)

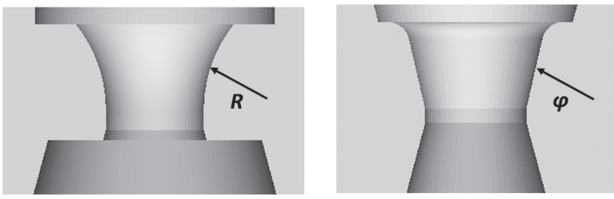

Figure 2 Die geometry No. 1 (left) with *R* =35 and No. 2 with φ = 26° (right)

RESULTS AND DISCUSSION

Dimensions of the multi-rifled tube, both experimental and simulated, were measured in the longitudinal section of the tube, as specified in Figure 3.

Table 1 **Final dimensions of multi-rifled tubes from simulations and optical 3D scanning**

	N.V.	Tol.	Die No. 1	Die No. 2	3D	A.D.
A	28,6	± 0,15	28,58	28,5	28,52	-0,02
B	16,1	± 0,15	16,08	16,02	16,00	0,02
D	6,27	± 0,57	6,22	6,17	6,3	-0,13
F	4,80	± 0,6	4,74	4,51	4,34	-0,17
S	8,30	± 1,04	8,70	8,98	9,38	-0,4
H	0,70	± 0,15	0,71	0,71	0,71	0
K	54	± 15	50	61	67	- 6
L	0,30	± 0,2	0,23	0,27	0,33	- 0,06
Ĺ	0,30	± 0,2	0,37	0,47	0,34	- 0,13
M	21,9	± 3,18	22,06	22,57	22,26	0,31
P	30	- 5	29,6	26,3	25,20	1,1

Table 1 description:

N.V. – Nominal value
Tol. – Tolerance
3D – 3D scan with Die No. 2
A.D. – Absolute difference/mm
A – Outer diameter/mm
B – Inner diameter/mm
D – Wall thickness/mm
F – Rib width (cross)/mm
S – Rib width (longitudinal)/mm
H – Rib height/mm

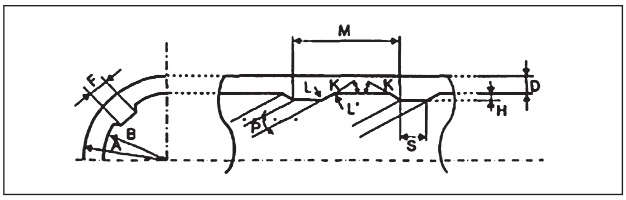

Figure 3 Selected dimensions of a multi-rifled tube – cross and longitudinal section drawing

K – Rib side angle/ °
L – Rib radius/mm
L` – Rib radius/mm
M – Rib pitch/mm
P – Lead angle/ °

The comparison of multi-rifled tube dimensions (Figure 3) according to different die geometries is shown in Table 1. Both die models meet the requirements according to customer specification. Although the filling of the ribs was fairly standard, a high risk of the damage of the material on the inner surface with possible cracking emerged due to the larger contact area between the inner surface of the tube and the plug (Figures 4, 5). This contact area difference was approximately 33 % with subsequent stress increase as well as the drawing force and plug load (Table 2). In this case, the plug – die combination with the die No. 2 did prove to be as effective as combination the die No. 1. Using die No. 2 for drawing of a multi-rifled tube, the reduction of the drawing force was almost 5 %.

Results of the experiment and simulation of multi-rifled tube drawing using die No. 2 are compared in the 5-th and 6-th column, Table 1. The 7-th column shows a

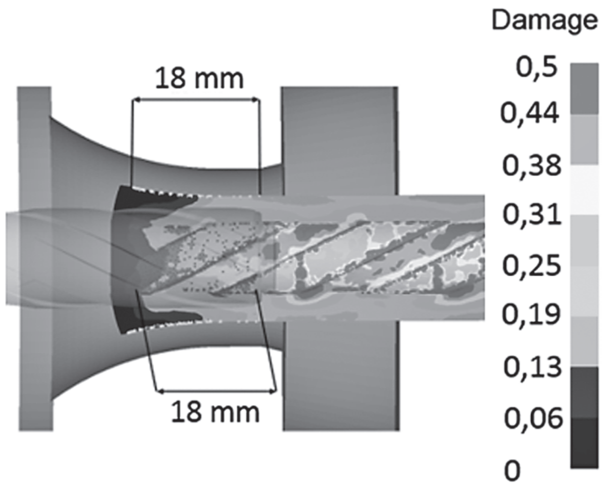

Figure 4 Damage distribution on the inner surface of multi-rifled tube using die No. 1

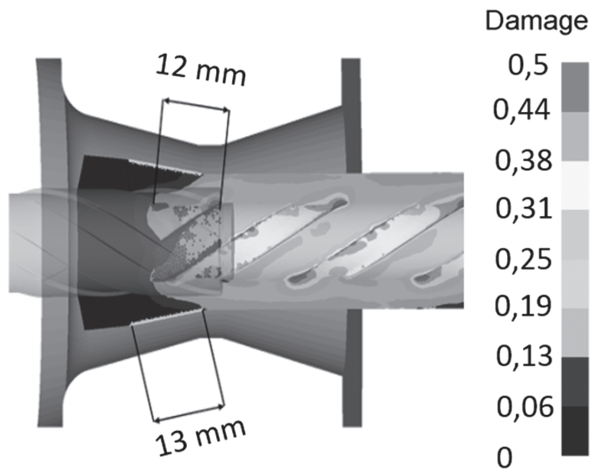

Figure 5 Damage distribution on the inner surface of multi-rifled tube using die No. 2

good agreement of consistency through the absolute difference.

Table 2 **Drawing force and axial load on a multi-rifled plug**

	Drawing force/kN	Plug load/kN
Die No. 1	189	6,3
Die No. 2	180	4,6

During forming, asymmetrical filling of the plug grooves was observed on a cross section of the tube (Figures 6, 7). This is the consequence of a combined rotational motion of the plug with high axial tension in the material during drawing. The tube material in the outbound groove does not fill the groove properly due to a dominant axial flow of the material in general and a receding groove side wall in particular. This is a key limiting factor of this forming technology.

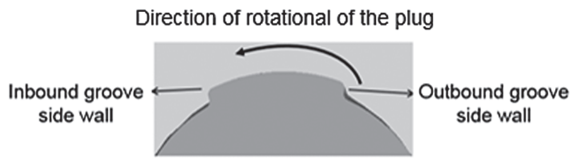

Figure 6 Rotation of plug in tube cross section

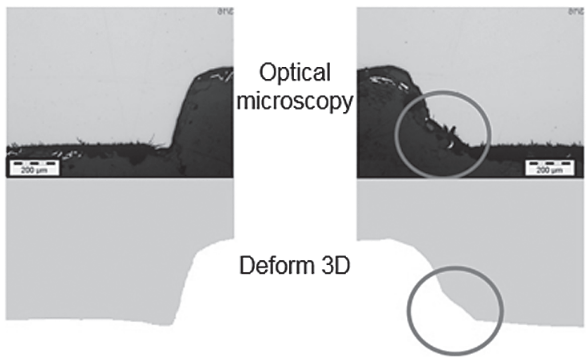

Figure 7 Comparing the simulation (bottom) and experiment (top): rib detail in tube cross section

CONCLUSIONS

Solving a technology optimization problem by means of numerical simulation proves to be a vital approach towards further innovations in precision tube production. The die No. 2 provided a better material flow while reducing the drawing force of drawing bench. Therefore, a lower plug load and a corresponding damage criterion values were detected to be more favourable. For numerical simulation of multi-rifled tube drawing, calculated dimensions show a good agreement with experimental results. Such a validated numerical model can serve as an efficient tool in further optimization of multi-rifled seamless tube production technology. For sensible numerical simulation of multi-rifled tube drawing it is decisive to use a high-quality computational mesh, preserving all intricate details of the inner grooving.

Acknowledgements

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Note: The responsible for English language is: P. Bucek, Brezno, Slovakia