EXPERIMENTAL VALIDATION OF NUMERICAL MODEL OF MULTI-RIFLED SEAMLESS TUBE DRAWING

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Abstract

The production of seamless steel multi-rifled tubes (i.e. tubes with multiple inner grooving) by means of cold drawing ranks among the most advanced cold forming production technologies. For this particular technology a hot rolled seamless steel tube serves as a feedstock for multiple cold drawing operations with a smooth plug. Then, the final drawing operation takes place, producing the grooving pattern on inner surface of the tube by means of a multi-rifled plug. In this paper, experimental validation of a numerical model of multi-rifled tube drawing is being presented. The model setup was prepared in DEFORM 3D simulation software with final tube dimensions of Ø 28.6 × 6.27 mm. The final tube dimensions from the experiment were obtained via optical 3D scanning technology. Comparing the measured quantities with the simulated ones, there was a very good agreement between the simulation and the experiment. Such a validated numerical model can serve as an efficient tool in further optimization of multi-rifled seamless tube production technology, bringing the producer a vital technological innovation into the traditional cold drawing production process.

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Keywords: Experimental validation, seamless steel tube, FEM, numerical simulation, multi-rifled tube, cold drawing

1. INTRODUCTION

Multi-rifled tubes (see **Figure 1**), 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 super critical pressures in coal-fired power plants.

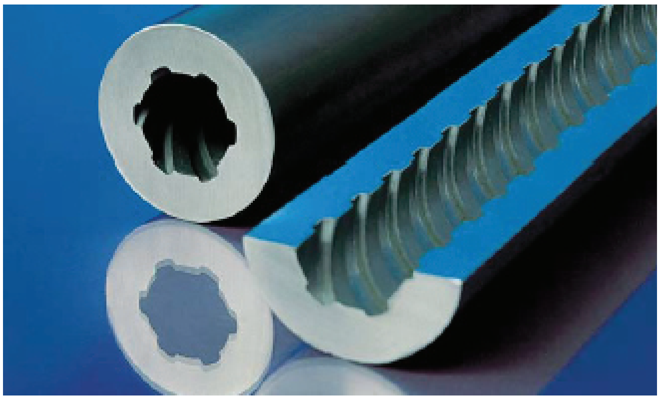

Figure 1 Multi-rifled tubes

In high pressure boilers, air bubbles are formed on the inner surface of tubes. This is caused by heat transfer from the tube walls and tends to create a steam film between the tube wall and the heated liquid. The steam film inhibits effective heat transfer between the tube and the liquid. If this exceeds a certain limit, the temperature of tubes will increase rapidly which can lead to damage of the tubes. In order to prevent steam film formation on the tube wall, the mass flow rate of the fluid should be increased or the fluid should swirl to maintain a good contact between the liquid and the tube wall [1].

Multi-rifled precision seamless steel tubes are produced by cold drawing technology, utilizing multiple drawing operations (sequences) with intermediate heat treatment. The final drawing operation produces the grooving pattern on inner surface of the tube by means of a multi-rifled plug. Given the demanding nature of production process and strict requirements placed on tube diameters, the process was being looked into by means of the finite-element method (later only as FEM) in DEFORM 3D simulation software. This numerical method provides an insight into the plastic deformation process and enables to investigate different physical fields in the modelled body, e.g. mechanical stress, deformation, deformation rate, damage criteria, material flow etc. The technological process can be further optimized based on simulation results.

2. MATERIAL, SIMULATION AND EXPERIMENT

In our experiment, a tube of grade T12 and input dimensions Ø 36 x 8 was used. 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. The drawing speed was 1.85 m / min. The experiment was conducted at room temperature. The multi-rifled tube dimensions after drawing were measured by 3D scanner GOM ATOS II and the data obtained were processed in order to obtain reverse-engineered CAD model of the tube [2].

Numerical model of tube drawing in DEFORM 3D was defined as to match the real operating conditions as closely as possible. The objects considered for modelling were the tube stock, the drawing die, the multi-rifled plug and the drawing carriage [3]. The tube stock was defined as a plastic object, which is suitable for modelling of cold forming process under certain conditions. A multi-rifled tube is, in comparison with a seamless tube, a very complex object when its shape is concerned. Therefore, strict dimensional requirements are being enforced when it comes to the actual production. The approximation of the tube geometry by means of FEM mesh is also very important in order to model all important geometric entities (ribs, grooves, rounded edges) in the shortest calculation time possible. In order to shorten the calculation time, it is possible to use the ¼ symmetry for the modelled domain. It is much more complicated to describe the inner surface of cold drawn tube (with multiple grooves) than the outer surface (smooth surface) in terms of FEM mesh size. In this model, weighting factors for FEM mesh creation were used so to place higher emphasis on surface curvature and strain distribution during remeshing. This approach is very effective and less time-consuming in actual calculation, as it requires fewer elements to describe less important regions, placing finer elements to more important regions according to the weights [4-7].

The multi-rifled plug rotates around its own axis during drawing due to the helical shape of the grooves. During simulation, the instantaneous angular velocity of the plug adjusts to the flow of material, i.e. drawing velocity. **Figure 2** shows the initial model setup before drawing. All the tooling was considered rigid and wear-free. The drawing velocity was v = 1.85 m/min. The simulation results were analysed in DEFORM 3D Post Processor, where all relevant dimensions for comparison with actual tube dimensions were measured.

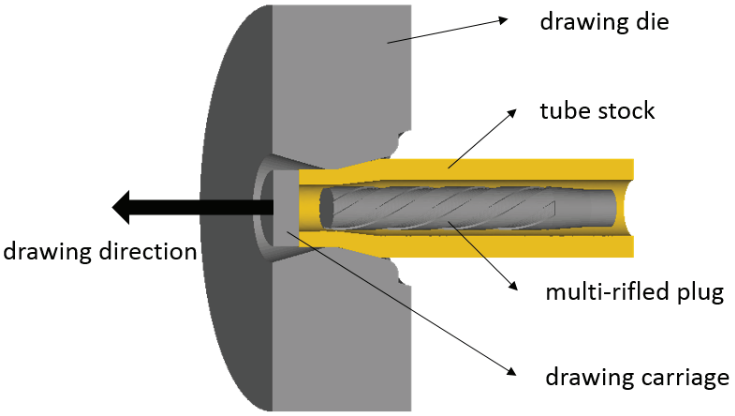

Figure 2 Initial model setup for numerical simulation of multi-rifled tube drawing

3. 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**.

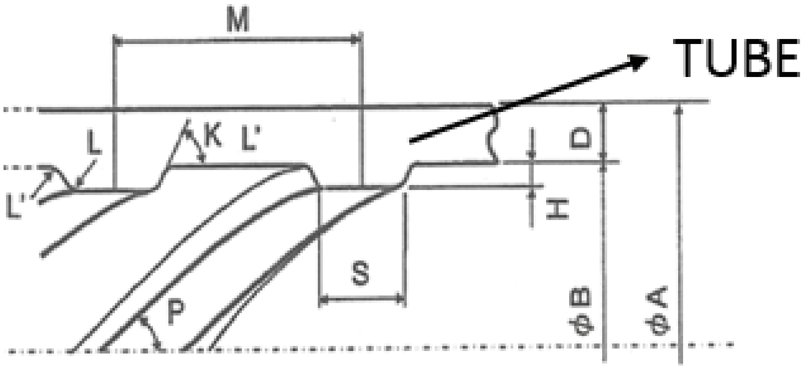

Figure 3 Relevant dimensions of multi-rifled tube - longitudinal section

Figure 4 shows the model geometry of multi-rifled tube in DEFORM 3D. Dimensions were measured as specified in **Figure 3**.

Figure 4 Longitudinal section of multi-rifled tube as simulated in DEFORM 3D

Figure 5 shows longitudinal section of multi-rifled experimental tube model obtained via 3D optical scanning. Dimensions were measured as specified in **Figure 3**. Experimental and simulated values are compared in **Table 1**. The results show a good agreement, enabling us to consider our numerical model a validated one.

Table 1 Comparison of experimental and simulation results

Label	**Description**	**Units**	*Numerical simulation*	*3D optical scanning*	*Abs. difference*
A	Outer diameter	mm	28.5	28.52	0.02
B	Inner diameter	mm	16.02	16	0.02
D	Wall thickness	mm	6.17	6.3	0.13
S	Rig width (longitudinal)	mm	8.98	9.38	0.4
H	Rib height	mm	0.71	0.71	0
K	Rib side angle	°	61	67	6
L	Rib radius	mm	0.27	0.33	0.06
L´	Rib radius	mm	0.47	0.34	0.13
M	Rib pitch	mm	22.57	22.26	0.31
P	Lead angle	°	*26.3*	25.2	1.1

Figure 5 Longitudinal section of multi-rifled tube model obtained via 3D optical scanning

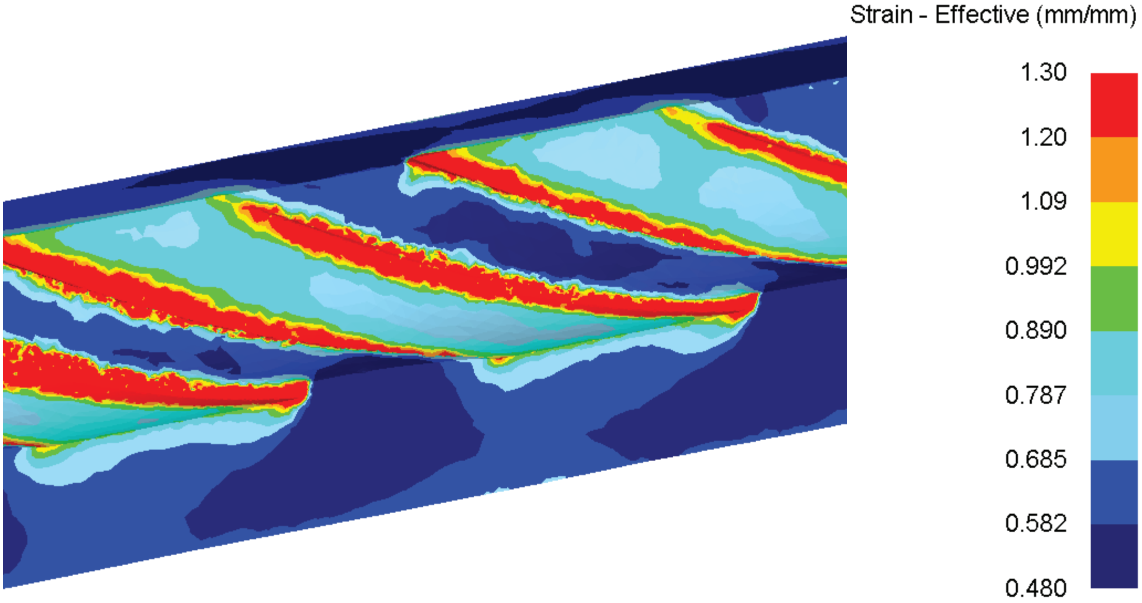

Figure 6 Distribution of effective plastic strain on the inner surface of multi-rifled tube

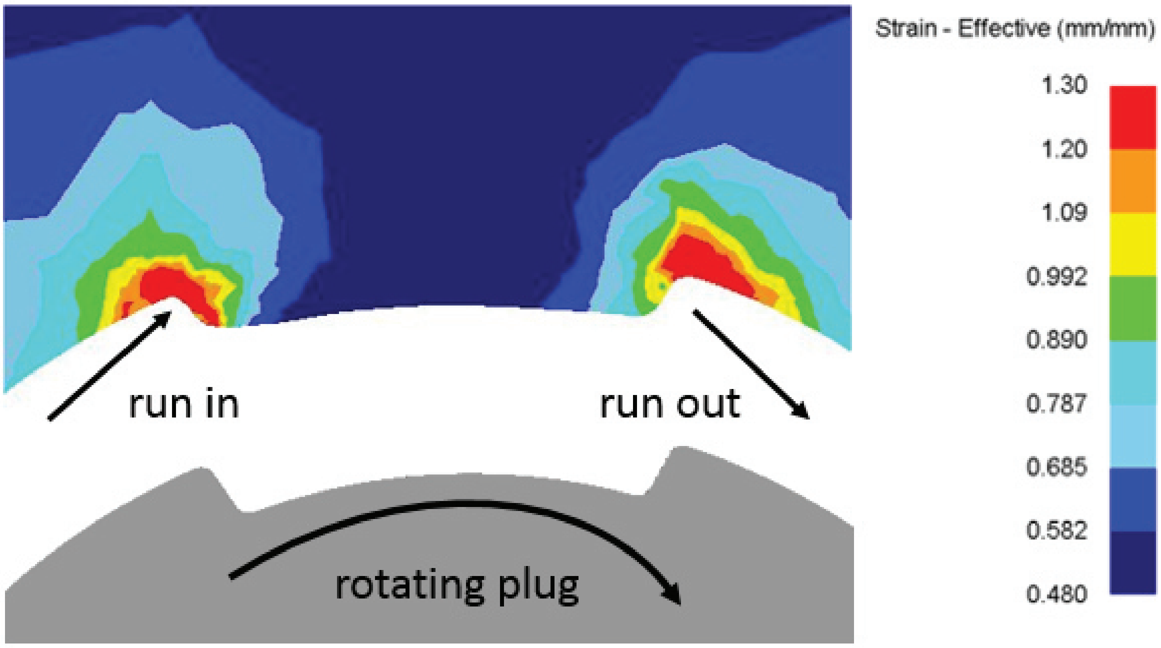

Figure 7 Distribution of effective plastic strain in tube cross section of tube thickness

Numerical simulation of multi-rifled seamless tube drawing shows a good agreement between calculated and experimental results, material flow as well as deformation. The maximum effective plastic strain was observed between the plug and the inner surface of the tube; see **Figure 6**, labels K, L, and L´. At those places, dimensions were measured. **Figure 7** shows strain distribution in tube cross section. We can observe an uneven contact between the grooves of multi-rifled plug and ribs of the tube. Therefore, it is not possible to achieve the same size of rib radius L, L´ and rib angle K.

4. CONCLUSION

For numerical simulation of multi-rifled tube drawing (Ø36 x 8.0 into Ø28.6 x 6.3), 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. Our next goal will be to optimize the process by varying the plug position with respect to the die, modifying the tool geometry and increasing the drawing speed, all of which will be investigated numerically in DEFORM 3D.

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