A STUDY ON THE TYPE OF MESH OF THE WORKPIECE USED FOR THE NUMERICAL MODELLING OF THE THREAD ROLLING PROCESS

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Abstract: *The methods of cold rolling of profiles are widely used in manufacturing industries to obtain pieces with complex shapes. Numerical simulation of these processes is a means to ensure, from the design stage, to obtain a desired quality of products. The simulation results are influenced by several factors including the workpiece mesh.*
This paper focuses on the establishing of the optimal mesh of the workpiece used in simulation on the cold rolling by in-feed method in order to balance the number of elements of the model, the computation time and the results of the simulation. The mesh of the workpiece was defined function of the main characteristic of the profile, the step p. The numerical models solved with the ABAQUS Explicit program.

Keywords: mesh the workpiece, numerical modelling, thread rolling

INTRODUCTION

Volumetric cold forming by in-feed method using two rolls (thread rolling) consists in forming the profile of the part with two correspondingly profiled rolls using the circular indexing of the workpiece and the in-feed working of the rolls, figure 1.

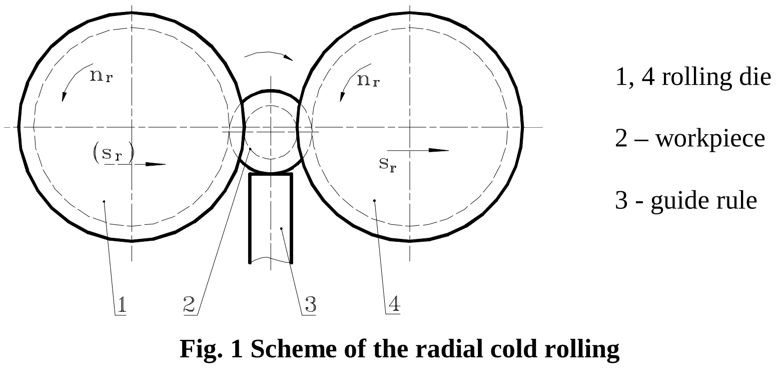


Fig. 1 Scheme of the radial cold rolling

The advantages of cold rolling (high productivity, superior mechanical properties, low roughness etc. [4], [5], [7]) are very well displayed in the case of obtaining parts on profiled surfaces, such as: threads, grooves, teeth, parts that can be found in various products of the automotive industry, aeronautics, appliances etc.

In the context of integrated manufacturing, simulation of working processes represents a useful tool in analysing the causes and preventing the problems that may come during the studied process. Numerical modelling of cold plastic deformation processes uses numerical models of the elements involved in the working process, workpiece – the elements of the technological system, and is followed by the numerical simulation where we observe the evolution of various parameters during the process: the stresses and strains of the deformed body, the way the material flows, the final shape and size of the product etc. [1].

Obtaining a numerical model to reproduce exactly the studied process is influenced by many factors, among which the mesh of the workpiece is a very important one [1], [2].

The objective of this paper is to set the way to mesh the workpiece in order to balance the number of elements of the model, the computation time and the results of the simulation.

EXPERIMENTAL PROCEDURE

The study was made for the thread rolling process of a circular (not helical) profile using the geometry of an axial section identical to the one of the ISO metric thread M20x2 STAS 6371 – 73 (the dimensions are presented in table 1).

Table 1 Dimensions of the ISO metric profile

Profile symbol	**p, [mm]**	**d, [mm]**	deviations, [mm]		**d_2, [mm]**	deviations, [mm]		**d_1, [mm]**	deviations, [mm]	
			e_s	e_i		e_s	e_i		e_s	e_i
M 20 x 2 – 6h	2	20	0	-0.28	18.701	0	-0.16	17.835	0	-0.289

Two materials were used for the study, OLC15 and OLC35, which are frequently used to generate these profiles through volumetric cold forming on machine parts.

A rolling device, fig. 2, conceived to be assembled on the lathe SN560, was used for the practical realization of the rolling process [4].

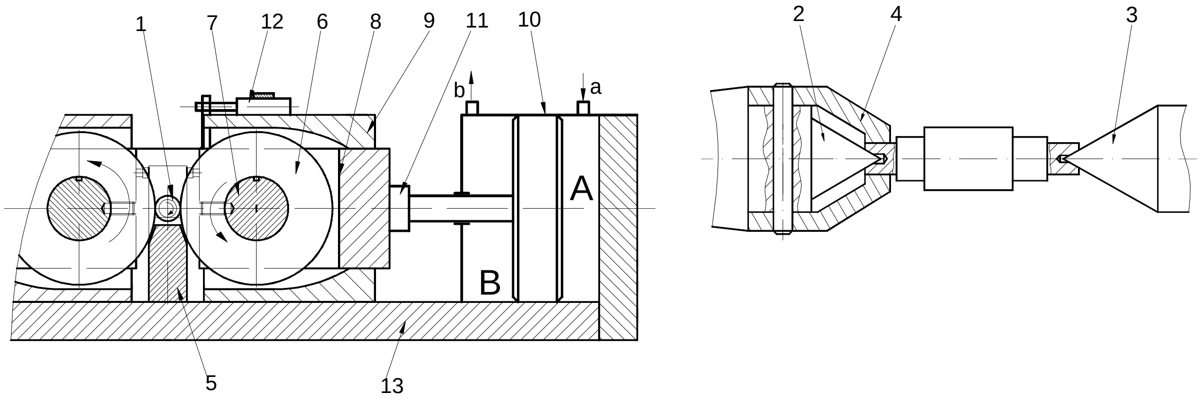


Fig. 2 Constructive scheme of the thread rolling device

The part to be rolled 1, is oriented between crests 2 and 3, set on the shaft, precisely on the loose headstock and is additionally sustained by guide 5. During the rolling process the part is moved by the rotation with the help of carrier 4 set on the peak of the lathe headstock.

The rolling process functions with two rollers 6, the device being conceived symmetrical to the part to be rolled. The rollers can rotate freely on the axes 7 which are set on the loose tool rest 8. The tool rest can move between the guides 9.

The movement of the tool rest is done with the help of hydraulic motors 10. The rolling process is obtained by rolling the part with a number of revolutions *n* and radially pressing the roller tools on the part using the two hydraulic motors. By varying the working pressure of the motors the forces of the radial pressure can vary as well.

The experimental system, figure 3, was used to record some values of the process (movement of the roller tools, force on radial direction and rotation of the tools). To control the movement limits of the rest on a radial direction there were used buffers that limit the movement of the rest, thereby the depth of the tools penetration into the part on a radial direction. The rotations of the part without a radial feed of the tools are controlled at the end of the rolling period by a sensor set at the end of the line through which the rolling can be stopped.

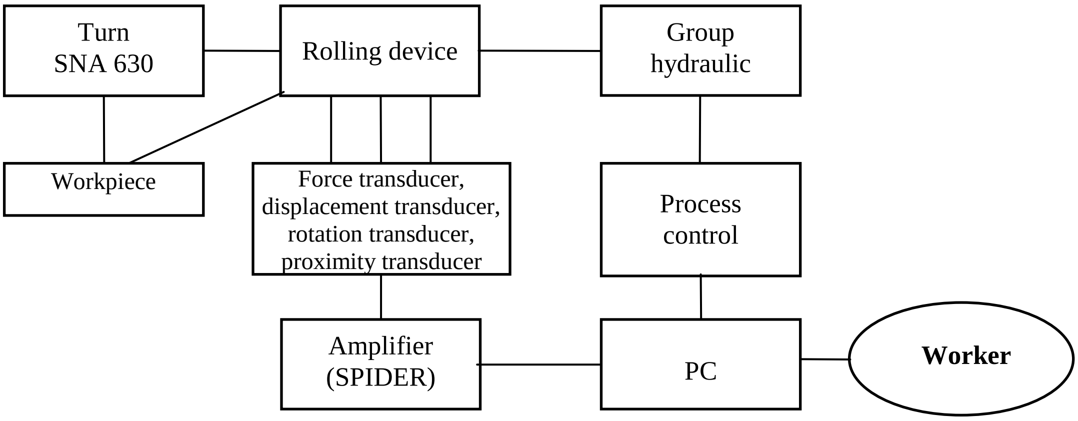


Fig. 3 The experimental system for the rolling of profiles

NUMERICAL PROCEDURE

For the simulation of the process, the input data (known elements) are the following:

- the shape and dimensions of the workpiece;
- the shape and dimensions of the rollers;
- the behaviour law of the material;
- the friction coefficients;
- the parameters of the working regime (number of revolutions of the tools, their feed, roll designing time).

To reduce the computation time, the workpiece used for the simulation has a simple cylindrical shape with a diameter established based on the law of the volume constant d_0 = 18.8 [mm] and the length of 22 mm (as long as the cylindrical surface of the real workpiece).

The rollers have a profile associated to the profile to be obtained; the external diameter has 120 mm.

The behaviour of the material is defined as follows:

- from a elastic domain with the Young's modulus E=210GPa and Poisson's coefficient ν = 0.3;
- from a plastic domain with the help of various behavioural laws (Ludwik, Voce, Hollomon-Voce-Johnson-Cook combinations)

The coefficients of these laws were experimentally determined using various mechanic tests (torsion and compression [3]).

The contact between the surfaces is a "surface-to-surface" type of contact, the friction coefficient between the tools and the workpiece is 0.3 and between the workpiece and the base is 0.01. These values were chosen based on literature review [2].

The parameters of the working regime, table 2, are introduced by defining the limit conditions:

- one of the rollers has two levels of freedom: feed on direction 1 and rotation on direction 3, fig. 4;
- the other roller has only one level of freedom, rotation on direction 3;
- the part is free and in contact with the base, its axis is set with 0.1 mm under the axis of the tools.

Table 2 The parameters of the working regime

Number of revolutions of the workpiece, [rot/min]	Deformation time, [s]	Roll designing time, [s]	Time to remove the parts, [s]
1600	0.53	0.095	0.2

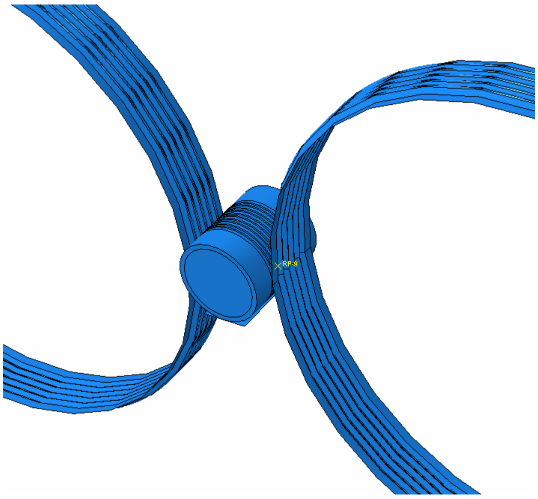


Fig. 4 The numerical model to generate thread profile

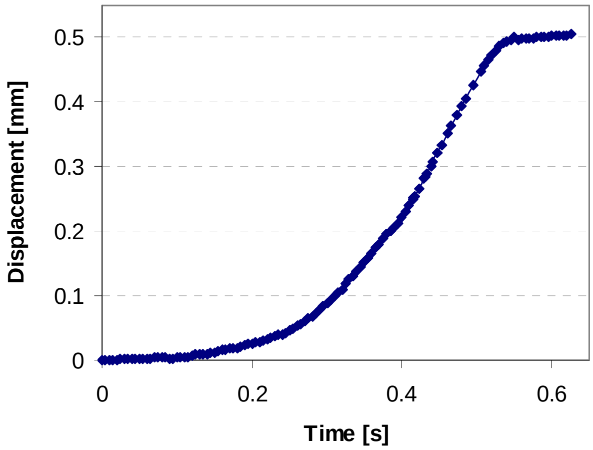


Fig. 5 The rolls in-feed curve (penetration curve)

The rolls in-feed curve (penetration of the material) used for the simulation is the one obtained experimentally, fig. 5.

The numerical models solved with the help of the ABAQUS Explicit program functioned on PC computer systems with Intel®QuadCore Q8400 processor, frequency 2.66 GHz and RAM memory in the laboratory of Physics and Material Mechanics, at the University of Metz, France.

RESULTS AND INTERPRETATIONS

The mesh of the workpiece influences the results of the simulation: if the elements are too big and the stresses are not correctly calculated, thus, making the strains and stresses have the same values on a wide surface (the one of the element mesh); while in practice the strains and stresses are different on the same surface.

Moreover, the number of elements where the workpiece is meshed is limited by the computation time which grows proportionally with it. Being a 3D simulation the mesh of the workpiece has to be achieved in a reasonable period of time and the number of elements has to be big enough to reproduce the real state of tensions and deformations of a deformed part. Achieving this balance represents the main objective of this paper.

First, we partitioned the workpiece in specific areas function of the degree of deformation considering the dimensions of the profile. Thus, the following mesh model was proposed:

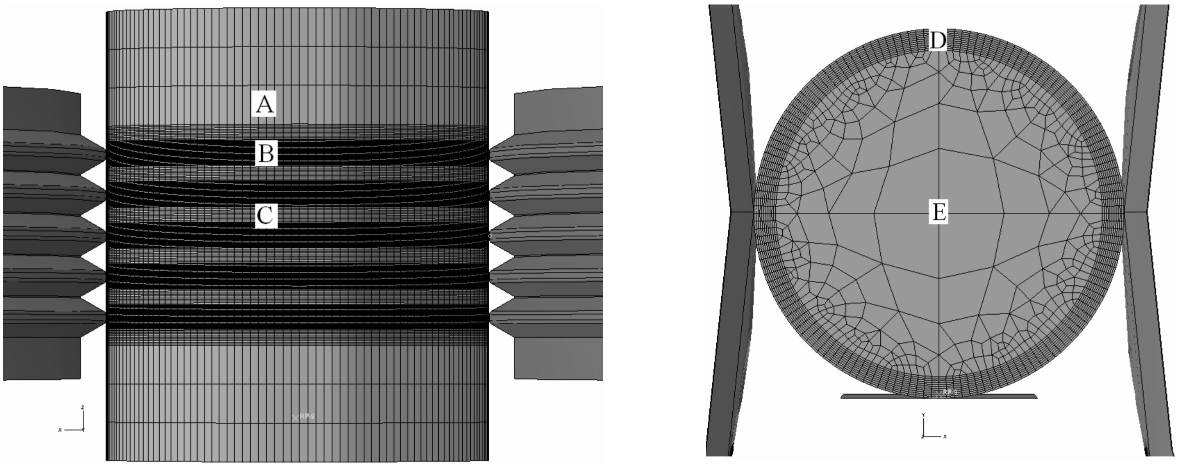
- on an axial direction we obtained three areas, fig. 6.a:
  - area A, with very small deformations, where the size of the elements can be very big,
  - area B, corresponding to the root of the profile, highly deformed, where the size of the elements has to be as small as possible;
  - area C, corresponding to the crest of the profile, has low deformations and an average size of the elements.
- on a radial direction we obtained two areas, fig. 6.b:
  - area D, associated to the superficially deformed layer, where the size of the element has to be small;
  - area E, corresponding to the core has small deformations and the size of the element can be very big.

For all the models in areas A, B, C and D we used solid hexahedral elements with 8 nodes and low integration – C3D8R, while area E was meshed in solid tetrahedral elements C3D4 with 4 nodes.

To generalize the mesh model, the dimensions of the elements specific to the five areas were established function of the main characteristic of the profile, the step *p*. During this stage the dimensions of the elements presented in table 3 were used.

Table 3 Dimensions of the finite elements for the first numeric model

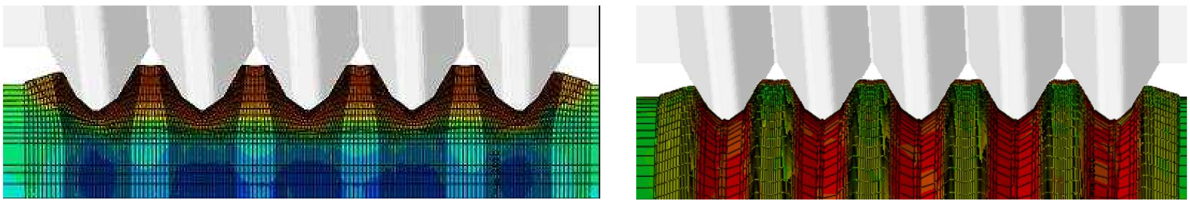
Model no	Total no of elements	Dimension of the element (length x width), mm			
		Area A	Area B	Area C	Area D
1	444400	2x0.4 p x p/5	0.4x0.04 p/5 x p/50	0.4x0.08 p/5 x p/25	0.4x0.1 p/5 x p/20



a) b)

Fig. 6 Mesh modulus of the first numeric model

Results obtained with this type of mesh led to obtaining a profile that did not correspond, fig. 7, a fact caused by the big size of the elements.



a) b)

Fig. 7 Shape of the profile obtained through model simulation 1: a) axial section; b) view

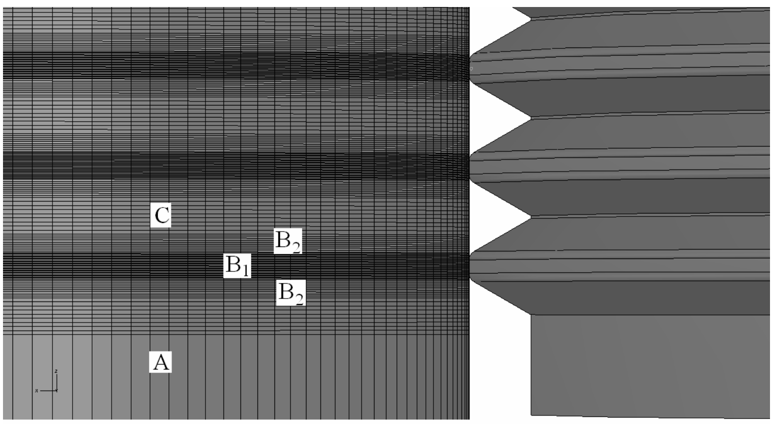


Fig. 8 Mesh modulus of the second numeric model

This is the reason why we moved to a different mesh of area B maintaining the sizes of the elements in the other areas, fig. 8:

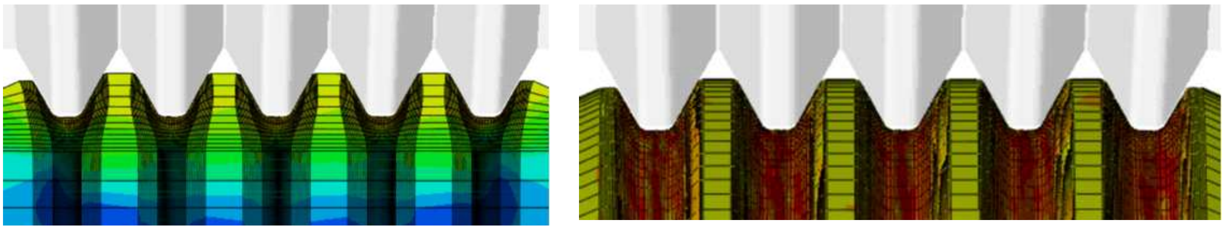
- area B_1, corresponding to the root of the profile with the biggest deformations is very smoothly meshed;
- area B_2, corresponding to the flank of the profile with big deformations is smoothly meshed.

Model 2 resulted, it had 584930 elements, but its rolling was impossible on the available computer system because of its insufficient memory. This aspect imposed a resize of the elements in areas C and D. This resize was achieved in successive stages, table 4, in order to reach the proposed objective: finding the best balance between the number of elements of the model, the computation time and the results of the simulation.

Table 4 Dimensions of the finite elements used for the studied models

<table>
<tr><th rowspan="3">Model no</th><th rowspan="3">Total no of elements</th><th rowspan="3">Calculating time, hours</th><th colspan="5">Dimension of the element (length x width), mm</th></tr>
<tr><th rowspan="2">Area A</th><th colspan="2">Area B</th><th rowspan="2">Area C</th><th rowspan="2">Area D</th></tr>
<tr><th>B_1</th><th>B_2</th></tr>
<tr><td>1</td><td>444400</td><td>63</td><td>2x0.4
p x p/5</td><td colspan="2">0.4x0.04
p/5 x p/50</td><td>0.4x0.08
p/5 x p/25</td><td>0.4x0.1
p/5 x p/20</td></tr>
<tr><td>2</td><td>584930</td><td>---</td><td>2x0.4
p x p/5</td><td>0.4x0.02
p/5 x p/100</td><td>0.4x0.04
p/5 x p/50</td><td>0.4x0.08
p/5 x p/25</td><td>0.4x0.1
p/5 x p/20</td></tr>
<tr><td>3</td><td>488114</td><td>123</td><td>2x0.4
p x p/5</td><td>0.4x0.02
p/5 x p/100</td><td>0.4x0.04
p/5 x p/50</td><td>0.4x0.8
p/5 x p/2.5</td><td>0.4x0.1
p/5 x p/20</td></tr>
<tr><td>4</td><td>293540</td><td>74</td><td>2x0.4
p x p/5</td><td>0.4x0.02
p/5 x p/100</td><td>0.4x0.04
p/5 x p/50</td><td>0.4x0.2
p/5 x p/10</td><td>0.4x0.2
p/5 x p/10</td></tr>
<tr><td>5</td><td>327410</td><td>80</td><td>2x0.4
p x p/5</td><td>0.4x0.02
p/5 x p/100</td><td>0.4x0.04
p/5 x p/50</td><td>0.4x0.08
p/5 x p/25</td><td>0.4x0.2
p/5 x p/10</td></tr>
</table>

For model 3 the dimension of the elements in area C increased to the maximum value. The number of elements decreased to 488114, the rolling time required 123 hours and the obtained profile resembled more to the experimental profile, fig. 9. Still, because of the fact that the crest of the profile is made of only one element the material flow was not entirely reproduced (fig. 10).



a) **b)**

Fig. 9 Shape of the profile obtained through model simulation 3: a) axial section; b) view

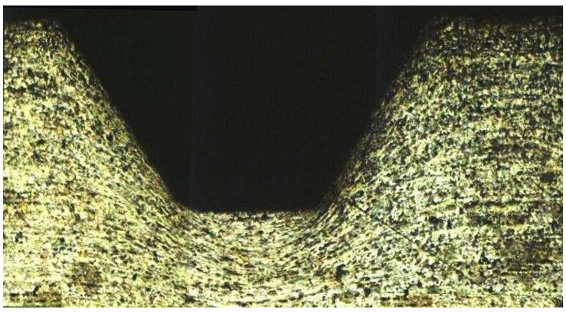
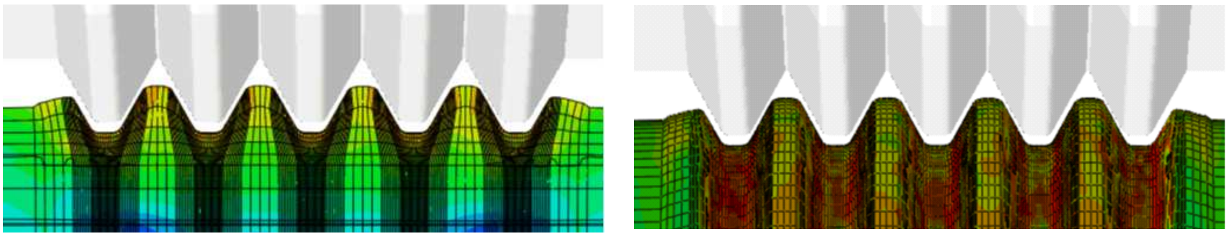


Fig. 10 Shape of the experimentally profile (metallography)

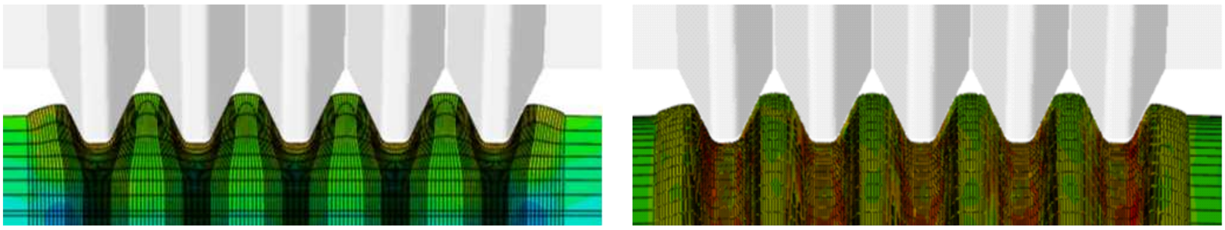
This is why for model 4 the dimension of the element in area C decreased; in order to decrease the total number of elements the dimension of the element in area D increased. The number of elements decreased a lot; the rolling time required 74 hours, but the profile obtained did not entirely reproduce the experimental profile (the radius of the profile's crest was too big, fig. 11).



a) b)

Fig. 11 Shape of the profile obtained through model simulation 3: a) axial section; b) view

For model 5 we returned to the minimum dimension of the element in area C while its dimension was maintained in area D. The number of elements was close to the one in the previous model, the rolling time required 80 hours and the profile obtained reproduced well the experimental profile, fig. 12.



a) b)

Fig. 12 Shape of the profile obtained through model simulation 3: a) axial section; b) view

Since this model reproduced the best the profile of the rolled part and the computation time was reasonable we estimate that this mesh model of the workpiece can be successfully used in simulating the studied process, but it can also be extended to other dimensions of this type of profile.

We specify that the shape of the profile obtained through simulation using the previous mesh models was not influenced by the behaviour laws of the material considered.

For the validation of the optimum mesh model the numerical simulation of the process was made for OLC15 material characterized based on Hollomon-Voce behaviour law ($\sigma_{PV} = \left[542.5\varepsilon^{0.135} + 217.6(1 - 0.99\exp(-9.91\varepsilon))\right]$), the coefficients were determined using the compression test.

We notice that the results obtained through numerical simulation are very close to those obtained experimentally, table 5, which enables the model validation.

Table 5 Comparative values

	Dimensions of the profile [mm]		Thread rolling force [kN]
	External diameter	Internal diameter	
Simulation	19.787	17.869	22.45
Experiment	19.857	17.818	21.62

CONCLUSIONS

The mesh models of the workpiece studied in the paper allowed us to establish the way they influence the performances of the simulation: the computation time, the shape of the resulting profile.

The optimum mesh model determined was partitioned in specific areas function of the degree of deformation of the material function of the shape of the profile. The dimensions of the finite elements of these areas were established function of the size of the profile spacing for each direction. This fact allows generalizing the mesh model for similar profiles.

Acknowledgements
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