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MODELLING OF MATERIAL FLOWS IN PIERCING TECHNOLOGY

MODELOWANIE PRZEPŁYWÓW MATERIAŁU W TECHNOLOGII DZIUROWANIA

The article summarises the modelling of the technological process of Mannesmann piercing in the configuration of the GreatMannesmann rolling mill in the Tube Mill of Třinecké Železárny using the approach of both mathematical modelling and numerical simulation. In accordance with the mathematical model of the given process, the formation of the cavity during the rolling in the numerical range is replaced by pre-drilling a billet of a specific size given by the mathematical model. The numerical simulations have shown an absolutely fundamental effect of the distribution of the initial temperature field of the billet on the actual piercing process. The billet with the initial inhomogeneous temperature field was subject to very strong transverse oscillations and significant spiral structures appeared in the distribution of all physical quantities. When simulating the piercing process on the Mannesmann piercer in the Tube Mill of Třinecké Železárny, parameterised by a mathematical model so as to take into account in the best possible approximation the influence of the cavity initiation sequence during the actual piercing, the simulation results were completely consistent with the predictions of the mathematical model of the submitted process calibration.

Keywords: *Mannesmann piercing, piercing process, billet temperature field*

W artykule podsumowano modelowanie technologicznego procesu dziurowania metodą Mannesmanna w walcarce GreatMannesmann w walcowni rur Třinecké Železárny z wykorzystaniem zarówno modelowania matematycznego, jak i symulacji numerycznej. Zgodnie z modelem matematycznym danego procesu, kształtowanie wgłębienia podczas walcowania w zakresie numerycznym zastępuje się wstępnym otworem w kęsie o określonej wielkości podanej przez model matematyczny. Symulacje numeryczne wykazały absolutnie fundamentalny wpływ rozkładu początkowego pola temperatury kęsa na rzeczywisty proces dziurowania. Kęs o początkowym niejednorodnym polu temperatury podlegał bardzo silnym oscylacjom poprzecznym i pojawiało się znaczące skręcenie kształtu w rozkładzie wszystkich wielkości fizycznych. Podczas symulacji procesu dziurowania w walcarce Mannesmanna w walcowni rur Třinecké Železárny, sparametryzowanej za pomocą modelu matematycznego, aby jak najlepiej uwzględnić wpływ sekwencji inicjacji wnęki podczas samego dziurowania, wyniki symulacji były całkowicie zgodne z przewidywaniami modelu matematycznego podanej kalibracji procesu.

Słowa kluczowe: *dziurowanie metodą Mannesmanna, proces dziurowania, pole temperatury kęsa*

1. INTRODUCTION

Třinecké Železárny, a.s. implements a number of technically and conceptually complex and unique orders of seamless pipes, especially in the field of OCTG and engineering, amplified by deliveries in a state of heat-treated processing. The interconnection of individual technological elements, from continuous casting of a circular format charge through its heating in a rotary-hearth furnace to two demanding forming processes, the piercing and pilger rolling process, significantly changes the microstructure in the whole volume up to the initial state – seamless tube. The stress-strain and temperature conditions significantly affect the surface quality and dimensional stability, especially in the most important formation operation of piercing on a piercing machine using the Mannesmann technology.

The modelling of material flows using Mannesmann's piercing technology, simulating the possible states of piercing machine settings of the Great Mannesmann rolling mill of the Tube Mill, according to

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the boundary conditions, approaching the possible real states, significantly helps in understanding the creation of defects, discontinuities and their prevention.

As part of an internal research task, a set of modelling was performed using the Forge software in MMV, spol. s. r. o. The aim was to obtain information from a numerical simulation on the development of billet geometry, material volume temperature and deformations during the piercing process for predetermined temperature conditions of the input material at homogeneous charge temperatures throughout the volume (1,230 °C, 1,280 °C and 1,330 °C) and temperatures inhomogeneous across the charge cross section (1,230 °C – 1,280 °C – 1,330 °C) depending on the chemical composition combination (structural steel, microalloyed steel and alloy steel) and the dimensions of the incoming material into piercing. To make it easier, the inhomogeneity of the temperature field is only across the charge cross section, not lengthwise.

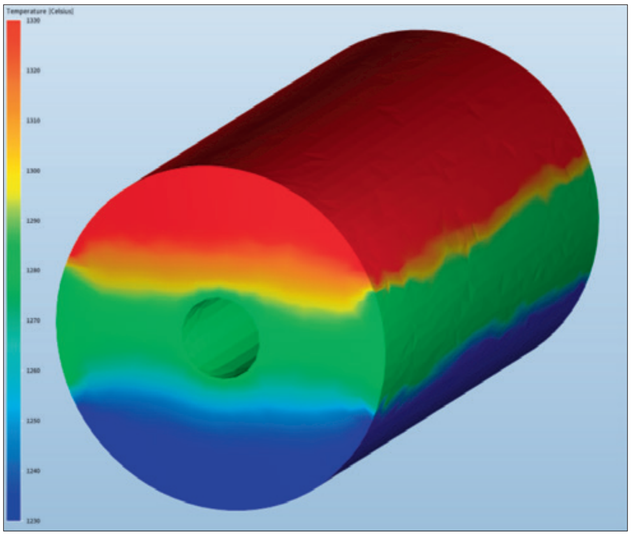

Fig. 1. Representation of the initial inhomogeneous temperature field of the billet. Thanks to the finite element network (FEN), the areas are not divided exactly into thirds

Rys. 1. Przedstawienie początkowego niejednorodnego pola temperatury kęsa. Dzięki sieci elementów skończonych (FEN) obszary nie są podzielone dokładnie na trzy części

2. MATERIALS AND METHODS

Based on the mathematical model applied by the method described in [1], a series of numerical simulations of Mannesmann piercing of continuously cast wire bars using the finite element method (FEM) in the Forge programme, version NxT 3.2 of the French company Transvalor was developed. The simulations capture the current real state of the Great Mannesmann rolling mill in VT TŽ a.s.

The piercing of continuously cast wire bars with the diameters of 410 mm and 470 mm from different types of steel and with different initial temperature fields was simulated. In addition to the homogeneous temperature field, an inhomogeneous field was also simulated, divided vertically by about one thirds of the billet, see. Fig. 1. The initial conditions of the individual simulations are given in Tab. 1.

A billet with both simulated diameters of 470 and 410 mm was pre-drilled. The pre-drilling diameter was in such a ratio to the diameter of the piercing mandrel, which was given by the mathematical model of the finite element method (FEM) simulation process itself. It is about controllability of the numerical simulation using a mathematical model that is already reproducible in terms of the model of the Mannesmann piercing process as a physical process. This is mainly a physically comprehensive capturing of the effect of real calibration of rollers in relation to the piercing mandrel when settingthe simulation parameters using the Forge programme.

2.1. NUMERICAL SIMULATION SETUP

The numerical simulation was compiled on the basis of real rolling conditions on the Great Mannesmann rolling millin the Tube Millof TŽ a.s. in 3D without using planes of symmetry. The setting of the roller positions in the numerical simulation was based on the experimentally measured positions of specific points in the roller bearings.

Table 1. Initial conditions of numerical simulations

Tabela 1. Warunki wstępne symulacji numerycznych

Simulation number	Inlet diameter (mm)	Steel marking	Initial temperature field of the billet	Temperature (°C)
1	470	S355	Inhomogeneous	Up to one third of the length of the billet: 1,230–1,280–1,330
2	410	S355	Inhomogeneous	Up to one third of the length of the billet: 1,230–1,280–1,330
3	410	X65/70 (L415NB)	Inhomogeneous	Up to one third of the length of the billet: 1,230–1,280–1,330
4	470	42CrMo4	Homogeneous	1,230
5	470	42CrMo4	Homogeneous	1,280
6	470	42CrMo4	Homogeneous	1,330
7	470	42CrMo4	Inhomogeneous	Up to one third of the length of the billet: 1,230–1,280–1,330

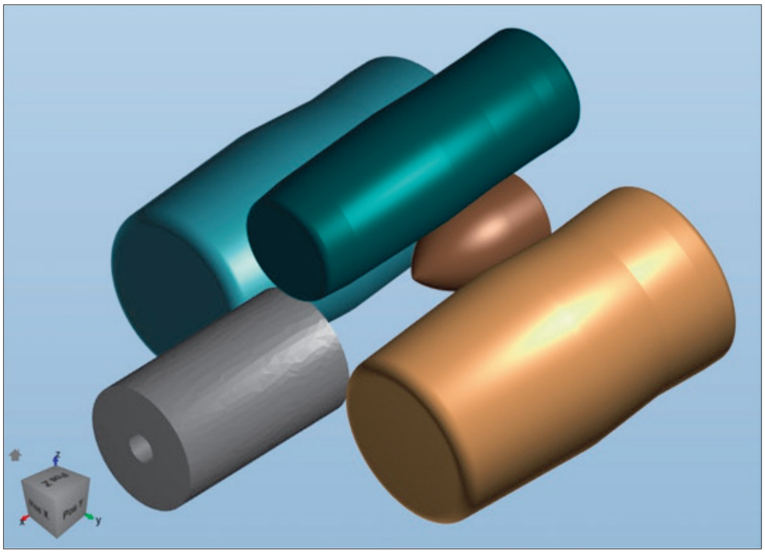

Fig. 2. General view of the simulation of Mannesmann piercing with marked axes on the left

Rys. 2. Widok ogólny symulacji dziurowania metodą Mannesmanna z zaznaczonymi osiami po lewej stronie

From the coordinates measured it was necessary, using transformation, to calculate the position and kinematics of the rollers for the Forge programme, because the position of the roller is defined in the Forge software by the position of its centre of gravity and the vector determining its axis of rotation. In total, the simulation consists of two driven (working) rollers, a support roller that is freely rotatable and a mandrel that is also freely rotatable and fixed in space (see Fig. 2).

Material models from the Forge software database were used in the simulation, where the strain hardening model is given by a simplified Spittel approximation [2], see equation (1)

$$\sigma(\varepsilon, \dot{\varepsilon}, T) = A e^{m_1 T} \varepsilon^{m_2} \dot{\varepsilon}^{m_3} e^{m_4/\varepsilon} \tag{1}$$

where:

ε – the equivalent deformation
$\dot{\varepsilon}$ – equivalent deformation rate
T – temperature
$\sigma(\varepsilon, \dot{\varepsilon}, T)$ – deformation resistance of the formed material.

The friction between the rollers and the rolled material was chosen from the predefined values of the Forge programme as “Tresca-very high”, described by the friction law according to Tresca with the value of the friction coefficient $\bar{m}$ = 0.8 [2].

The friction between the mandrel and the rolled material was set as “water + graphite”, described by the law according to Coulomb and Tresca with the values of the friction coefficients $\bar{m}$ = 0.3 and μ = 0.15.

The heat transfer coefficient between the working rollers, the mandrel and the rolled material was set as “medium for hot forming” with a value of 10 $\text{kW}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$. The surrounding environment was non-flowing air at a temperature of 20 °C with a heat transfer coefficient between the rolled material and air of 10 $\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$.

The working rollers and the mandrel were defined as absolutely rigid with a constant temperature of 250 °C. These values are based on the recommended values for setting boundary conditions for hot rolling simulations in Forge.

A boundary condition was introduced to get the billet into the engagement of the working rollers, which was defined as a time-varying force acting on the billet in the rolling direction. After 0.2 to 0.5 s (depending on the inlet size), it reached zero values, so the rolled material was not pushed then.

3. NUMERICAL SIMULATION RESULTS

The facts found by numerical simulations can be summarised in the following key points:

a) The inhomogeneous distribution of the initial temperature causes a strong transverse oscillation of the rolled material during rolling

In all simulations with the initial inhomogeneous temperature field of the billet, its significant transverse oscillation was found during the simulation. These transverse oscillations also cause significant fluctuations in the force exerted by the rolled material on the mandrel against the rolling direction.

Fig. 3 shows the time dependence of the force component acting on the mandrel in the rolling direction for a homogeneous and inhomogeneous temperature field. It can be seen that the mandrel is exposed to strong vibrations (oscillations with a longer period) during the rolling of the inhomogeneously heated billet, which are not caused by discretization into the network elements, as is the case with a homogeneously heated piece.

The values are negative because the applied force is oriented in the X direction, i.e. against the rolling direction. The unit of force is in the weight equivalent of a ton (9.8 kN).

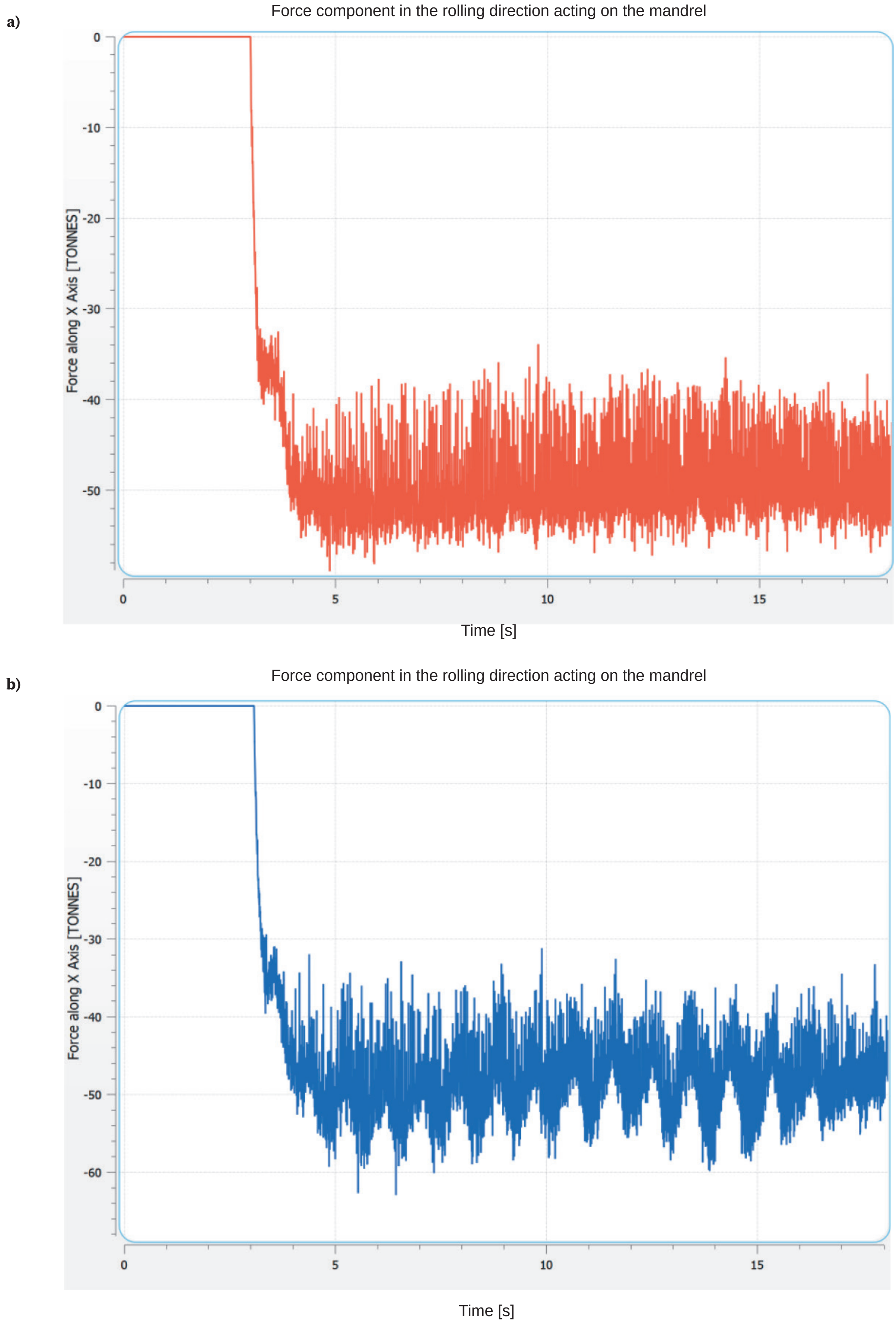

Fig. 3. Graph of the dependence of the force component in the rolling direction acting on the mandrel over time for a homogeneous (a) and inhomogeneous (b) initial temperature field of a billet with an inlet diameter of 410 mm

Rys. 3. Wykres zależności składowej siły w kierunku walcowania działającej na trzpień w czasie dla jednorodnego (a) i niejednorodnego (b) pola temperatury początkowej kęsa o średnicy wlotowej 410 mm

b) The inhomogeneous distribution of the initial temperature causes a formation of spiral structures in the distribution of physical quantities

With the transverse oscillations, the formation of spiral structures in the monitored physical fields also occurs in inhomogeneously heated billets. This applies to inlets with a diameter of both 470 mm and 410 mm. The most pronounced spiral structure is shown by the temperature distribution; to a smaller extent, it is also present in the distribution of the tube wall thickness and the equivalent deformation, as shown in Fig. 4.

A very prominent spiral structure is in the distribution of temperature (Fig. 4a), the tube wall thickness (Fig. 4c); less prominent is in the distribution of the equivalent deformation (Fig 4b).

c) The wall thickness of the rolled product with the same rolling mill setting depends on the material being rolled

This fact is well seen when comparing the thicknesses of walls along the length of the rolled product for pieces with an inlet diameter of 410 mm. A graph comparing thicknesses of walls of rolled products for both Group A materials (S355 and X65/70 – L415NB) is shown in Fig. 5. It can be clearly seen that the X65/70 rolled steel has a greater tube wall thickness.

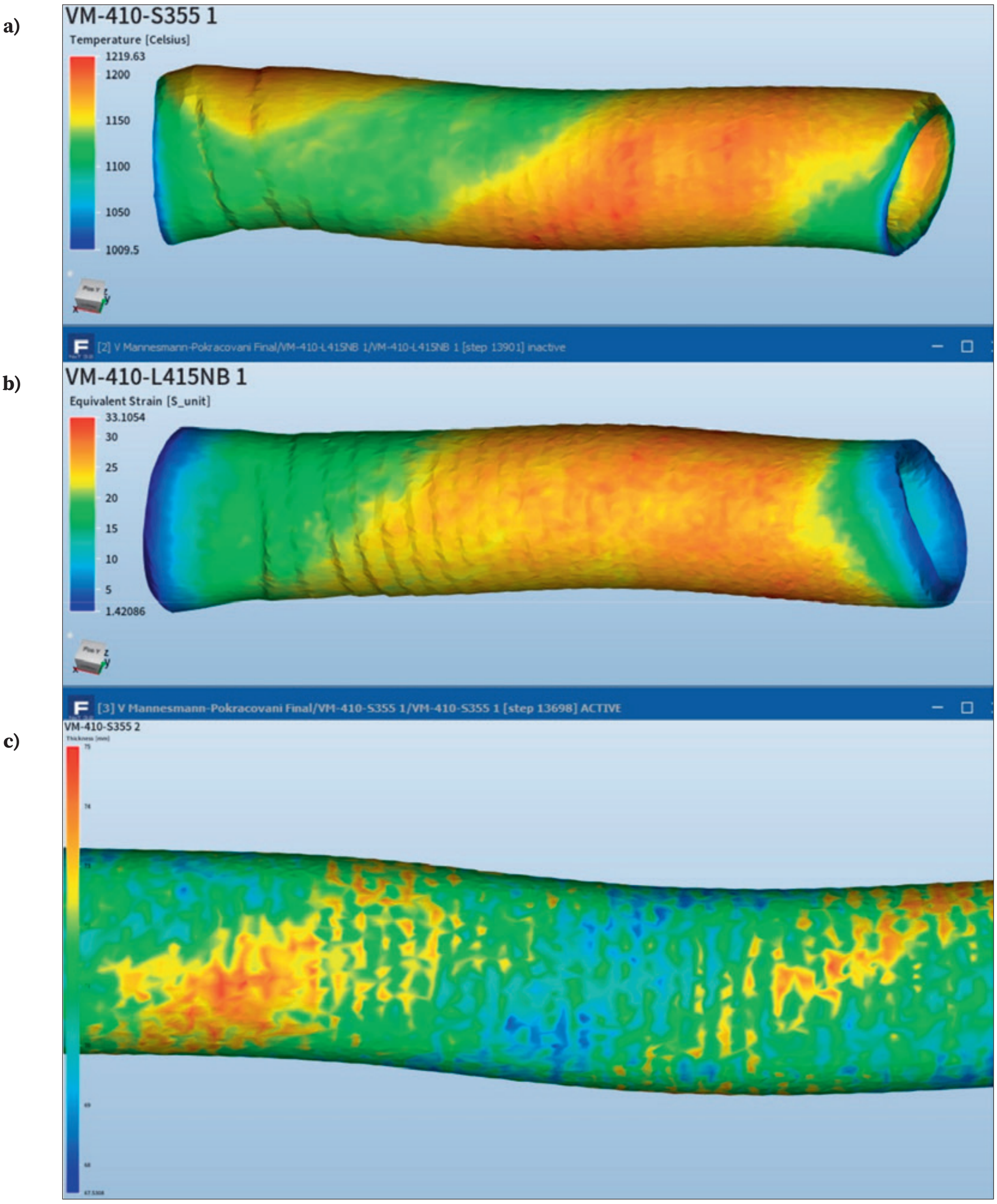

Fig. 4. Formation of spiral structures in the distribution of physical quantities on the surface of a rolled product with an inlet diameter of 410 mm

Rys. 4. Powstawanie struktur spiralnych w rozkładzie wielkości fizycznych na powierzchni wyrobu walcowanego o średnicy wlotowej 410 mm

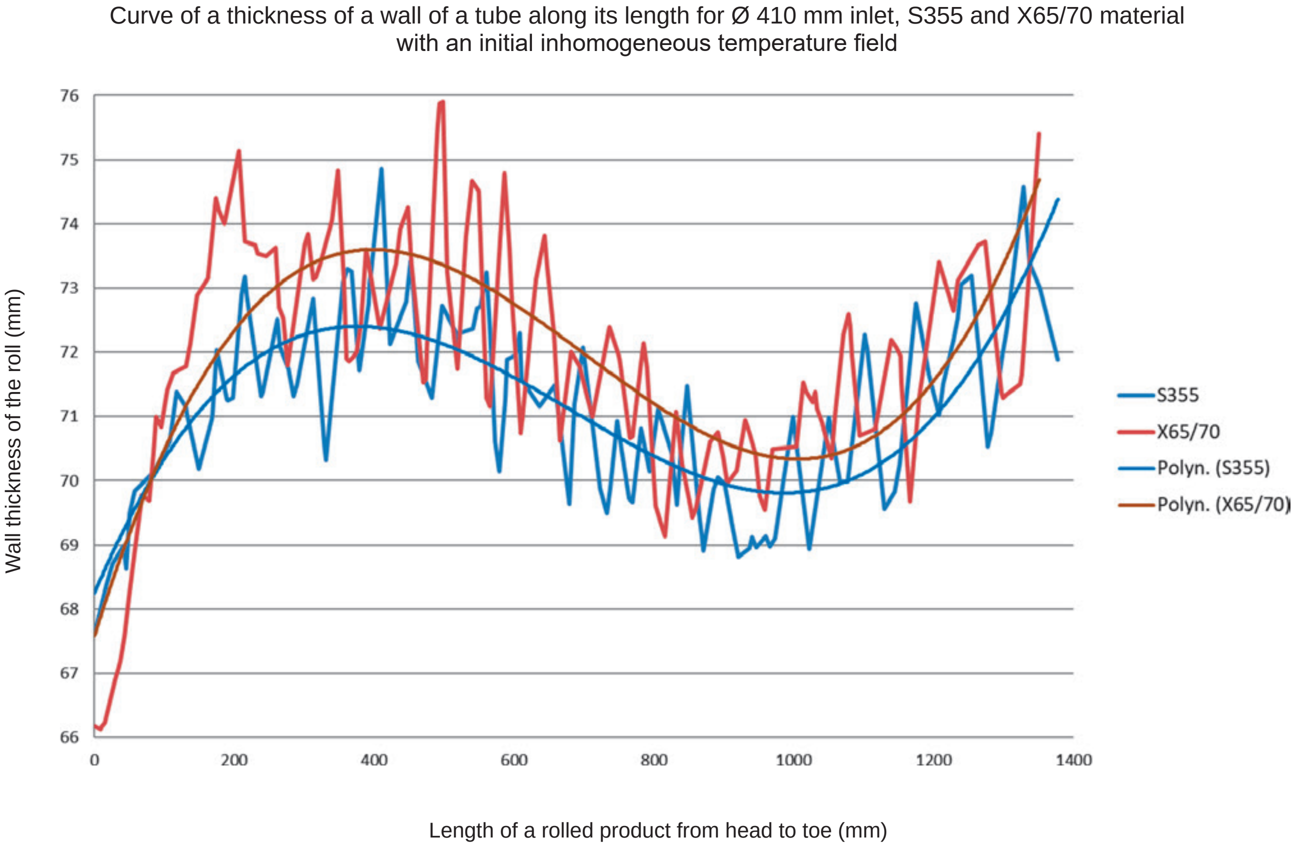

Fig. 5. Comparison of thicknesses of walls of rolled S355 and X65/70 steels. After interpolating the dependences of the polynomials, the greater wall thickness of X65/70 is clearly visible

Rys. 5. Porównanie grubości ścianek walcowanych stali S355 i X65/70. Po interpolacji zależności wielomianów widać wyraźnie większą grubość ścianki X65/70

d) The variation of the curves of the thicknesses of walls of a tube along its length depends on the inlet diameter

If we compare the curves of the thicknesses of walls of rolled products along their lengths for inlets with a diameter of 410 mm and 470 mm, we find that much larger oscillations in the values of wall thicknesses are for inlets with diameters of 410 mm. In the following graph (Fig. 6), the undulations can be well compared by comparing the approximations with the polynomial. Forgreater objectivity,the measurement was performed along the two lines on the surface of the tube. Significant oscillations with a smaller period and a larger amplitude are due to the characteristic spiral notching on the surface of rolled products with an inlet diameter of 410 mm.

4. CONCLUSION

The role of the initial inhomogeneity of the billet temperature field on the development of the geometry, structure and physical properties of the rolled material during piercinghas proved to be crucial here, regardless of the S355, X65/70 and 42CrMo4 materials used. This is because there are kinematically excited oscillations as a result of the instability of the system calibration due to the temperature field of the rolled material. These oscillations are the source of the longitudinal undulations of the rolled material as a whole, accompanied by the formation of spiral structures in the distribution of physical properties with respect to its surface. These spiral structures are reinterpreted by the mathematical model of the FEM simulation process in the role of the so-called spiral vortex flows of media between two oppositely rotating cylindrical surfaces of the rolled material, as in the Taylor-Couette flow between two rotating rollers [1]. These vortexes are then the last stage of the flow before the system enters chaos. In order to obtain real results, it was necessary to suppress the strong tendency to computational divergence by careful selection of the finite element network and the position of the mandrel. With smaller billet diameters of 410 mm vs 470 mm, the development of the geometric and physical irregularities of the rolled material shows greater “dynamics”, which is reflected in particular in the increase of unevenness in the distribution of the wall thickness. This is probably, with the same principle of temperature unsteady calibration, given by the lower resistance of the inertial forces.

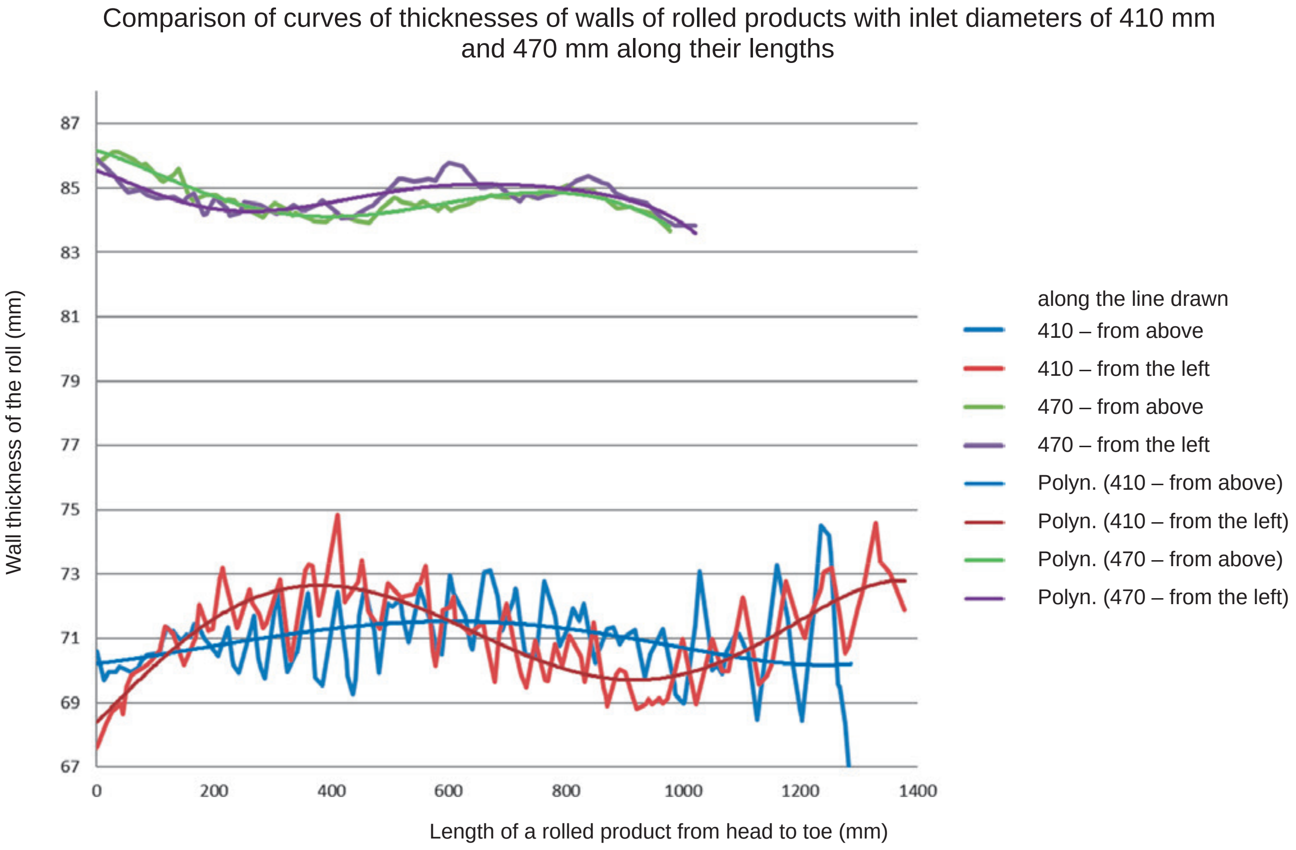

Fig. 6. Comparison of the curves of thicknesses of walls of rolled products with a diameter of 410 mm and 470 mm along their length from head to toe. The measurement was performed along two lines

Rys. 6. Porównanie krzywych grubości ścianek wyrobów walcowanych o średnicy 410 mm i 470 mm na ich długości od góry do dołu. Pomiar prowadzono wzdłuż dwóch linii

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