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NUMERICAL ANALYSIS OF THE SKEW ROLLING PROCESS FOR RAIL AXLES

ANALIZA NUMERYCZNA PROCESU WALCOWANIA SKOŚNEGO OSI WAGONOWYCH

The paper describes a new method for producing stepped rail axles. The method is based on the skew rolling process. With this method, the product is formed by three tapered rolls located every 120° on the perimeter of the billet. Positioned askew to the centerline of the billet, the rolls rotate in the same direction and with the same velocity. At the same time, they get closer together or go apart depending on the desired cross sectional reduction of an axle step. In addition, the workpiece is shifted lengthwise relative to the rolls by the translational motion of the workpiece-holding chuck. In order to verify the designed method for producing rail axles, a series of numerical simulations were performed using the Simufact.Forming v.12 simulation software. The numerical modeling enabled the determination of maps of the effective strain and temperature in the finished product as well as variations in the loads and torques during rolling. The numerical results unambiguously confirm that the skew rolling method can be applied to form parts of considerable dimensions (the modeled axles had a length of 2146 mm and their maximum diameter was 202 mm).

Keywords: Skew rolling, rail axle, FEM

W artykule opisano metodę wytwarzania stopniowanej osi wagonowej bazującą na procesie walcowania skośnego. W metodzie tej wyrób kształtowany jest za pomocą trzech rolek stożkowych, rozmieszczonych na obwodzie wsadu co 120°. Rolki te ustawione są skośnie względem osi wsadu, a w trakcie kształtowania obracają się z jednakową prędkością w tę sa-mą stronę oraz jednocześnie zsuwają lub rozsuwają się – w zależności od redukcji przekroju poprzecznego kształtowanego stopnia osi. Dodatkowo, wyrób kształtowany przesuwany jest wzdłużnie względem rolek, w wyniku ruchu postępowego uchwytu utwierdzającego jeden z jego końców. Sprawdzenia poprawności założonej koncepcji kształtowania osi wagonowej dokonano w drodze symulacji numerycznej wykonanej w programie Simufact.Forming v.12. W efekcie wykonanych obliczeń uzyskano mapy intensywności odkształcenia i temperatury w ukształtowanym wyrobie oraz wyznaczono przebiegi sił i momentów w trakcie walcowania. Jednoznacznie potwierdzono możliwość kształtowania wyrobów o dużych gabarytach (długość osi wynosi 2146 mm, a jej średnica maksymalna 202 mm) metodą walcowania skośnego.

1. Introduction

Stepped axles and shafts are widely applied in automotive industry, railway industry and engineering. At present, these types of parts are manufactured mainly by means of metal forming methods such as: open die forging, closed die forging, rotary swaging, cross-wedge rolling (CWR). A special attention should be paid to CWR process, which gains in popularity [1, 2]. It happens because this method has numerous advantages (large efficiency, relatively low material consumption, environment friendly method), and its main disadvantage (complex designing process of wedge tools) is successively eliminated due to application of possibilities provided by computer modeling. Aiming at increasing efficiency of the CWR process, a new variant of this process was worked out, that is multi wedge cross rolling (MWCR), in which a part is formed by a few pairs of wedges at the same time [3-7]. In the MWCR process tools length was shortened, yet it resulted in their more complicated shape (extreme wedge construction should consider a product elongation due to central wedges acting) and a considerable increase of forces and forming moments, which values very often exceed the permitted scopes of machines used in industrial conditions.

The MWCR method was tried to be used for forming of large long parts, such as rail axles. However, the conducted research works [8, 9] showed that realization of this rolling case would require constructing a rolling machine of large dimensions (wedge diameter would be 1.6 m) and power. Hence, searching for new, effective ways of rail axles forming, which are nowadays manufactured from free forged forgings, is still up-to-date issue. Skew rolling by means of three conical rolls, which is discussed in this paper, seems to be such a method.

2. The rule of skew rolling by means of three rolls

The schema of skew rolling process by means of three conical rolls is shown in Fig. 1. In this process rolls are placed

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askew, at the angle θ to the product axis, they rotate with the same velocity in the same direction. Moreover, rolls have the possibility of moving up and down (towards billet axis), depending on the reduction of cross section of the shaft formed step. Yet, rolls spacing is synchronized with axial movement of handle in which the formed part is mounted.

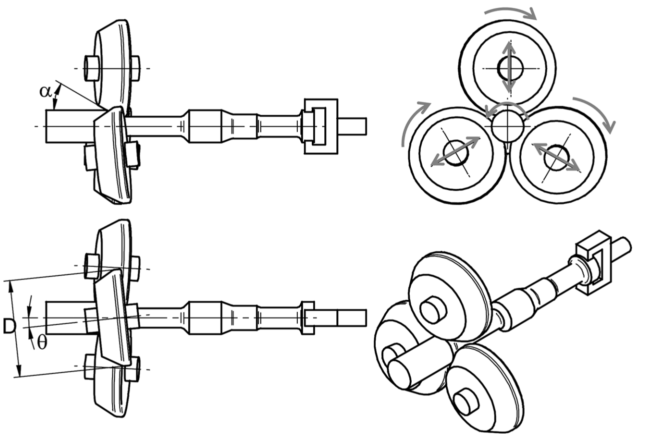

Fig. 1. Schema of the rolling process by means of three conical rolls of long axi-symmetrical products

Presented way of axles and long shafts forming was worked out in the former Soviet Union [10]. Steering of rolls placing took place by means of templet. The development of steering and automatics resulted in possibility of present numerical realization of rolls and handle movement synchronization. It should be, however, noticed that applying the same rolls provides opportunity of various products forming, which shape will depend only on appropriate programming of rolls and handle movement. Versatility of rolling realized according to this schema results also from the fact that it is profitable in conditions of small scale production, even elementary one.

3. Numerical model of skew rolling process of a rail –coach axle

In order to show technological possibilities of skew rolling, numerical analysis of the forming process of a rail axle, shown in Fig. 2 was made. This element is applied in rail wheels sets and it has the length about 10.6 times larger than its maximal diameter, and extreme steps have the diameter 33% smaller than the maximal diameter. The weight of the analyzed rail axle forging equals 407.8 kg.

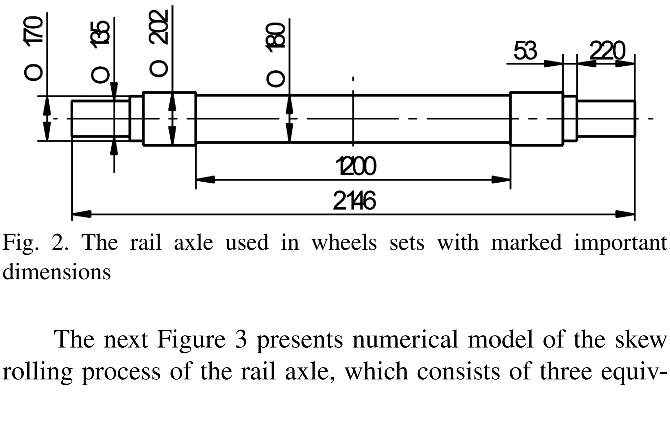

Fig. 2. The rail axle used in wheels sets with marked important dimensions

The next Figure 3 presents numerical model of the skew rolling process of the rail axle, which consists of three equivalent rolls (of diameter 500 mm and angle α =30°) and billet (of dimensions Ø202×1725 mm and weight 433 kg). In the process model the handle was omitted, in the place of which billet side surface was fixed, replacing the handle axial movement by rolls axial feed (this action did not change the process kinematics and made conducting numerical simulation easier). It was assumed that during forming rolls rotate in the same direction and with the same velocity 60 rot/min and they move linearly in the axial direction (with velocity v_x) and in the direction of billet axis (with velocity v_r). Distributions of velocities v_x and v_r assumed in calculations are given in Fig. 4.

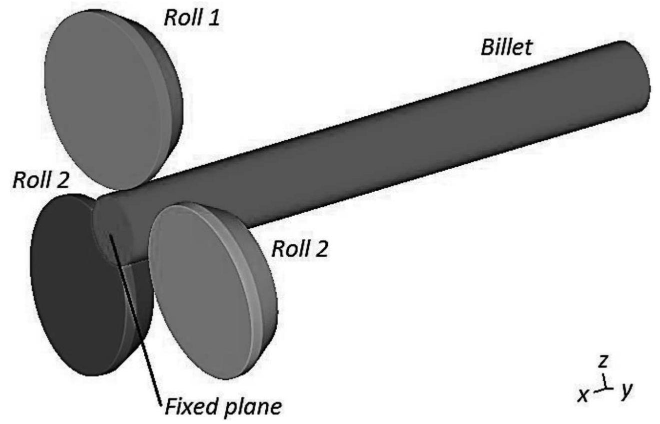

Fig. 3. Numerical model of the skew rolling process of the rail axle

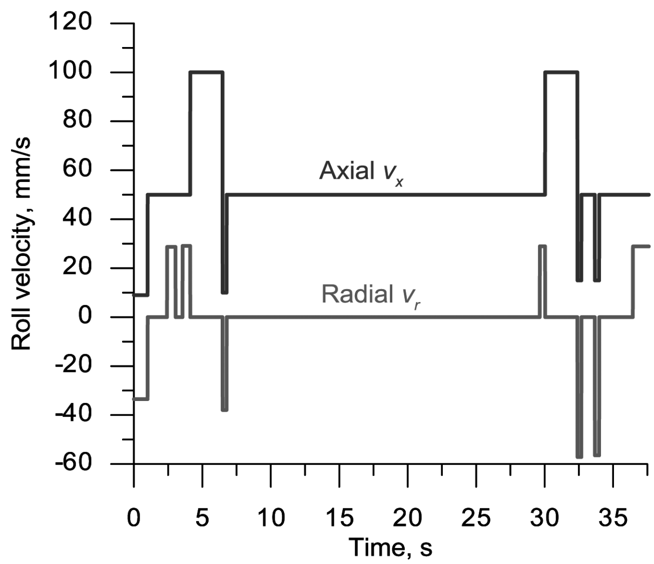

Fig. 4. Assumed in calculations distributions of rolls linear velocities: in the axial direction v_x, in the radial direction v_r

It was also assumed that the axle is made from steel C45, which material model is determined by the equation:

$$\sigma_p = 4105 e^{(-0.00355T)} \varphi^{(-0.00013T-0.00507)} e^{\left(\frac{-0.00002T-0.0281}{\varphi}\right)} \dot{\varphi}^{(0.00018T-0.02416)}, \tag{1}$$

where: σ_p – yield stress [MPa], ϕ – strain intensity, $\dot{\varphi}$ – strain velocity [1/s], T – temperature [°C]. Comparison of the rest of parameters assumed in calculations contains: friction factor on the material-tool surface of contact 0.95, rolls temperature 50°C, billet temperature 1120°C and coefficient of heat exchange between material and rolls 20000 W/m^{2}K.

The discussed numerical model was made applying commercial software Simufact.Forming v.12, basing on finite element method. This software was used by the Authors many times for the analysis of skew and cross rolling processes [11-17] and calculations results were in good conformity with experimental research results, verifying these calculations.

4. Results of numerical simulation

In the result of conducted numerical calculations it was stated that there exists possibility of manufacturing rail axle of assumed shape by means of skew rolling with three rolls. Figure 5 shows how the product shape changes depending on the rolling process advancement. Particular steps of axle are formed one by one, yet, at its ends allowance appears which should be removed (e.g during machining). The presence of the first allowance is connected with clutching of the formed product by the rolling mill drawing handle, however, allowance at the second end of axle is the effect of superficial material flow, leading to head funnel. It should be also noticed that allowance is not large as technological waste constitutes only 5.8% of billet material volume. It is important that apart from large slenderness the axle does not undergo bending, which is, by no means, the result of axial tensile stresses present in its area between rolls and handle (fixation).

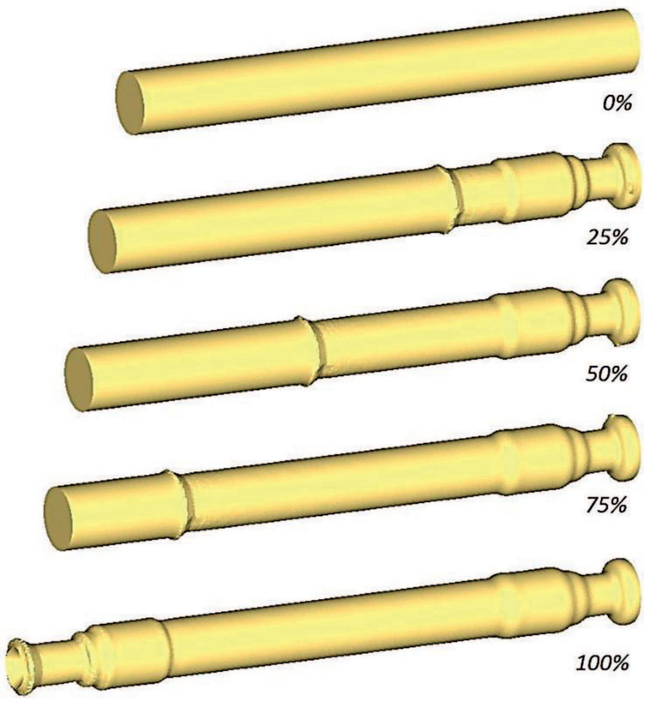

Fig. 5. Changes of the rail axle shape in the skew rolling process, depending on the process advancement

Figure 6 presents effective strain distribution on the surface and in axle axial section. The analysis of the obtained distribution shows that strains distribute in a liner way and have the largest value near the surface and the smallest in the axial area (the result of friction force acting on tools – material surface of contact). Moreover, a considerable dependency between strains size and step diameter reduction was observed (increase of strains is connected with increase of diameter reduction). The observed strains distribution is regarded as typical for skew and cross rolling processes [1, 2].

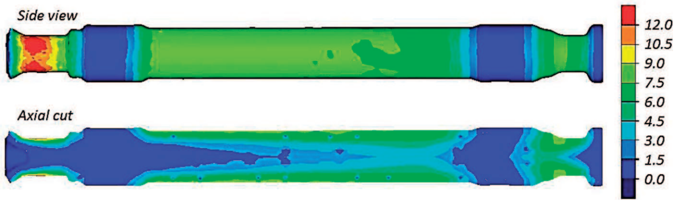

Fig. 6. Distribution of strain intensity in the rail axle obtained in the skew rolling process with three rolls

The assumed forming time of rail axle is 37.6 s, hence it is relatively long. However, during forming tools contact with material locally and there is no considerable decrease of material temperature, which remains within the scope proper for metal forming processes in hot conditions in the whole volume of product. This is confirmed by temperature distribution shown in Fig.7. It should be also remembered that heat losses transmitted into tools and environment are compensated by heat generated due to interchanging of friction work and plastic strain work.

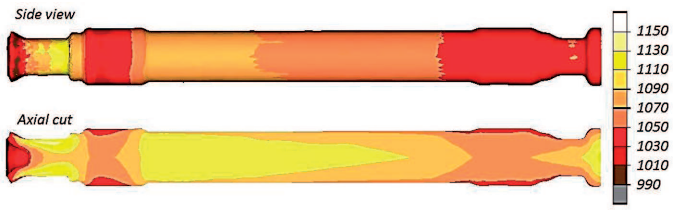

Fig. 7. Temperature distribution (in °C) in the rail axle obtained in the skew rolling process with three rolls

Interesting information can be achieved from the rolling process force parameters analysis, which comparison is shown in Fig. 8. It is visible that forces sizes on roll (radial and axial forces) strongly depend on cross section reduction. The larger the reduction is, the bigger are force parameters. It should be emphasized that forces maximal values (below 550 kN for the radial force and below 120 kN for the axial force) are relatively small in comparison with dimensions of the rolled product. This means that the rolling mill applied in the skew rolling process can have light construction. Maximal force on the handle (equal three times the value of axial force on roll) is also relatively small and its achieving will not require application of hydraulic feeder of large power.

Similar conclusions can be drawn after the analysis of rotary moment distribution on the forming roll, which is presented in Fig. 9. The moment course is strongly dependent on axis diameter reduction and runs almost identically as the radial force distribution. Maximal value of the rotary moment on roll was 32 kNm, yet, it was a momentary value. Therefore, it is justified to equip the skew rolling mill with flywheel as it will favor decrease of the power of the mill main drive.

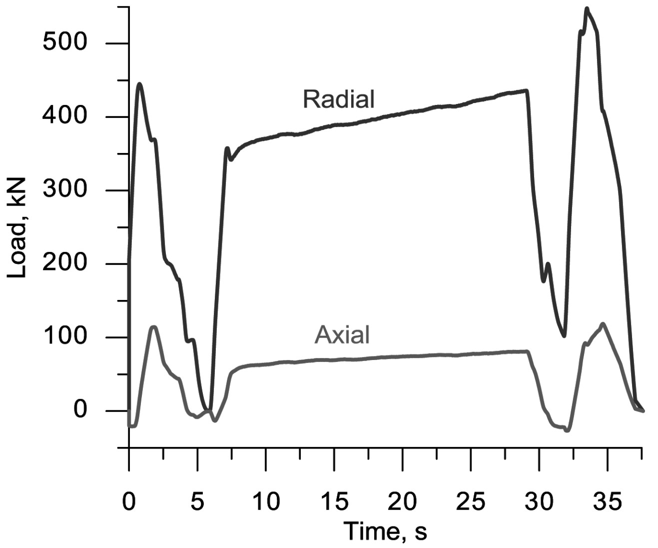

Fig. 8. Distribution of radial and axial forces acting on roll in the skew rolling process with three rolls of the rail axle

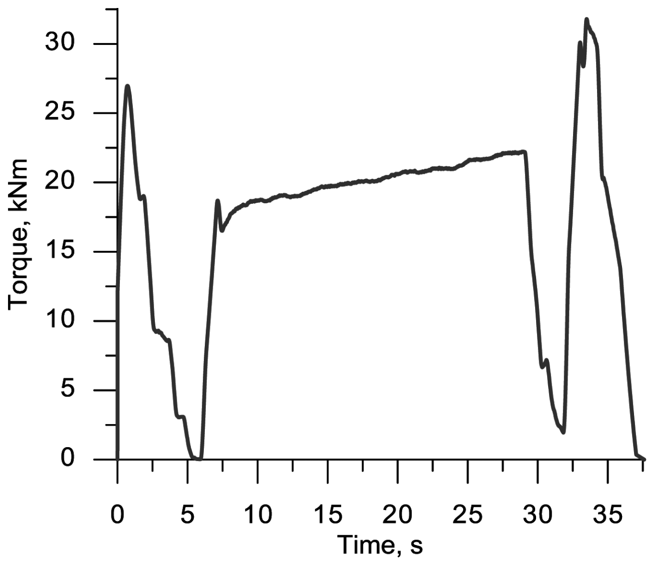

Fig. 9. Rotary moment on roll distribution in the skew rolling process with three rolls of the rail axle

5. Conclusions

On the basis of conducted numerical analysis the following conclusions can be drawn:

- By means of skew rolling method large axi-symmetrical products can be formed, such as rail axles;
- The skew rolling method is characterized by large versatility (one rolls set can be used for rolling products of various shapes);
- Strains in the rolled askew product are of laminar character (annular) in the way characteristic for cross rolling processes;
- Although forming time is relatively long, there is no material cooling hindering the forming process course;
- Force parameters (forces and rotary moment) in the skew rolling process reach moderate values in comparison with dimensions of the formed parts;
- Research works within the scope of skew rolling of long axi-symmetrical products (including rail axles) should be continued and expanded on hollowed parts.

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REFERENCES

[1] Z. Pater, Development of Cross Wedge Rolling Theory and Technology. Steel Research International, “Special edition: Metal Forming 2010”, 25-32 (2010).

[2] Z. Pater, Cross-Wedge Rolling. In Comprehensive Materials Processing; Button, S. T., Ed.; Elsevier Ltd. **3**, 211-279 (2014).

[3] J. Zhao, L. Lu, The application of multi-wedge cross wedge rolling forming long shaft technology, Applied Mechanics and Materials **101-102**, 1002-1005 (2012).

[4] J. Zhou, Z. Yu, Q. Zeng, Analysis and experimental studies of internal voids in multi-wedge cross wedge rolling stepped shaft, The International Journal of Advanced Manufacturing Technology **72**, 1559-1566 (2014).

[5] B. Sun, X. Zeng, X. Shu, W. Peng, P. Sun, Feasibility Study on Forming Hollow Axle with Multi-wedge Synchrostep by Cross Wedge Rolling, Applied Mechanics and Materials **201-202**, 673-677.

[6] X. Shu, Z. Li, W. Zu, Bending Analysis and Measures of the Forming of Automobile Semi-axle on Cross-Wedge Rolling with Multi-wedge, Applied Mechanics and Materials **184-185**, 75-79 (2012).

[7] Z. Pater, Multi-wedge cross rolling of balls. Journal of Iron and Steel Research International **20**, 10, 46-50 (2013).

[8] X. Shu, X. Wei, Ch. Li, Z. Hu, The influence rules of stress about technical parameters on synchronous rolling railway axis with multi-wedge cross-wedge rolling, Applied Mechanics and Materials **37-38**, 1482-1488 (2010).

[9] B. Hu, X. Shu, P. Yu, W. Peng, The Strain Analysis at the Broadening Stage of the Hollow Railway Axle by Multi-wedge Cross Wedge Rolling, Applied Mechanics and Materials **494-495**, 457-460 (2014).

[10] E.R. Sor, New rolling processes. Ed. Metalurgizdat, Moscow 1960 (in Russian).

[11] Z. Pater, A. Tofil, Experimental and Theoretical Analysis of the Cross-Wedge Rolling Process in Cold Forming Conditions, Archives of Metallurgy and Materials **52**, 2, 289-297 (2007).

[12] Z. Pater, The Analysis of the Strain in Parts Formed by Means of the Wedge-Rolls Rolling (WRR), Archives of Metallurgy and Materials **50**, 3, 675-690 (2005).

[13] J. Tomczak, Z. Pater, J. Bartnicki, Skew rolling of balls in multiple helical impressions, Archives of Metallurgy and Materials **58**, 4, 1072-1076 (2013).

[14] Z. Pater, J. Tomczak, J. Bartnicki, M.R. Lovell, P.L. Menezes, Experimental and numerical analysis of helical-wedge rolling process for producing steel balls. International Journal of Machine Tools & Manufacture **67**, 1-7 (2013).

[15] Z. Pater, T. Bulzak, A. Tofil, J. Tomczak, Helical-wedge rolling of balls. Kovarenstvi, 47, 84-87 (2013).

[16] Z. Pater, Analysis of the helical-wedge rolling process for producing a workholding bolt. Metalurgija **53**, 4, 653-656 (2014).

[17] Z. Pater, Analysis of the Helical-Wedge Rolling Process for Producing a Long Stepped Shaft. Key Engineering Materials **622-623**, 893-89 (2014).