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Research of Speed Parameters of the Ring Rolling Process

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ABSTRACT

Hot ring rolling is a method of forming ring products with large diameters in relation to the cross-sectional dimensions. This process is a complex incremental metal forming process. It is characterized by high dynamics and continuous change of shape of the rolled ring. Important process parameters are the rotational speed (and the peripheral speed dependent thereon) and the infeed speed of the main roll. In industry, the goal is to be as efficient as possible, so it makes sense to use the highest possible speeds in the process. An important issue is to determine the ratio of the peripheral speed of the main roll to the infeed of that roll. If the ratio of these speeds is too low, the ring is distorted due to the occurrence of slippage between the tools and the ring being shaped. The objective of the research presented in this study was to determine the limiting ratio of infeed speed to peripheral speed of the main roll. Based on the tests conducted, a range of values for the ratio of the two speeds of the main roll at which the process can be performed properly was determined.

Keywords: ring rolling process, infeed speed, peripheral speed, limiting speed ratio.

INTRODUCTION

The products obtained by hot ring rolling are widely used in various industries. They are characterized by a significant ratio of diameter dimensions to cross-sectional area. The advantages of ring rolling include a smooth surface, low overages, significant material savings and most importantly, short production time [1–4]. It is precisely because of the short production time that speed parameters are of paramount importance. This fact makes the design of the technology in question relatively complex. It is difficult to control the dimensional accuracy of the products obtained in the process. The velocity parameters have a great influence on the efficiency of the process and the correct course of the process. It is natural for industries to strive for the highest possible efficiency and therefore to use the highest possible speeds in the process.

In the specialized literature, it is difficult to find guidelines for plotting the maximum values of the main roll peripheral speed and its infeed. It should also be noted that the proper ratio of these parameters is very important.

Lin and coauthors [5] analytically tried to determine the correct parameters during the ring rolling process, they included: maximum tool recess, maximum infeed speed, tool dimensions and dimensions the forging being shaped. During the radial-axial process, researchers found that in order to ensure uniform and stable ring growth, the growth rate of the outer diameter must be constant and the infeed speed must gradually decrease as the ring thickness decreases, this applies to both cold [6] and hot [7] processes. Another solution is to use a variable speed of rotation of the main roll allowing a constant speed of the shaped product [8]. Such execution of radial rolling process is not possible due to dynamics and due to technical limitations of rolling mills.

Wanga et al. [9] in their work, found that low tool feed rates result in significant voids in the structure, which are concentrated in the middle of the product wall thickness. This argues in favor of using the highest possible infeed speed. Surdacki et al. [10] in their study presented the effect of the infeed speed of the moving tool at constant main roll speed on the process. The research allowed them to conclude that the greater the value of the infeed of the shaping roller, the cross-section of the ring has a shape similar to a rectangle. Lower tool feed rate per revolution increases the "fish-tail" defect and results in greater material loss and a less efficient process. Uchibori et al. [11] observed that the circumferential velocity of the workpiece during the radial-axial rolling process is close to that of the main roll; however, the velocity decreases as the process progresses. In addition, they observed that at the beginning of the process, the circumferential velocity of the ring is slightly higher than the circumferential velocity of the main roll; then the velocity gradually decreases, and at the end of the rolling process, it is lower than the circumferential velocity of the main roll. Slip plays an important role in the ring rolling process. Gontarz and Surdacki in [12] studied this problem in radial ring rolling. Based on an analysis of the reduction of the ring cross section, they found that slip could be predicted. The occurrence of this undesirable phenomenon depends on the ratio of the peripheral speed to the infeed speed of the main roll. Experimental results showed that the reduction of ring thickness and the probability of slippage increase with the increase of the ratio of the main roll's infeed speed to its rotational speed.

Much of the available scientific literature focuses only on numerical simulations [7–9, 13–18], and bench testing is lacking.

The literature review shows that despite works investigating the ring rolling process in terms of tool speed, the problem of selecting the values of individual speeds, and in particular their mutual ratio, has not been thoroughly investigated. Therefore, it was considered reasonable to undertake a study to determine the limits of peripheral speed and infeed of the main roll during radial rolling of steel rings.

RESEARCH METHODOLOGY

A schematic of radial hot ring rolling is shown in Fig. 1. A initial ring *3* is placed on the mandrel *2*. During the process, the mandrel rotated around its axis. Ring shaping occurs due to the action of the main roll *1*, which moves radially with velocity V_1 towards the mandrel, causing a change in the cross-sectional area of the charge. By rotating at a speed n_1, it causes the ring to rotate and the mandrel to rotate. It should be noted that the most important parameters affecting the correct course of the process are the rotational speed n_1 and the infeed speed V_1 of the main roll. Too high an infeed velocity V_1 (for a given rotational speed n_1) causes slippage between the main roller and the

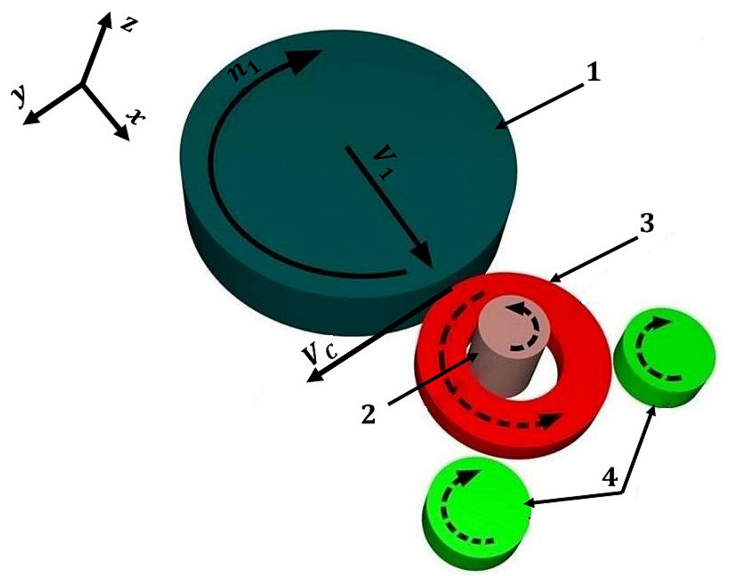

Fig. 1. Scheme of radial ring rolling; 1 – main roll, 2 – mandrel, 3 – shaped ring, 4 – calibrating rollers [10]

ring to be shaped; the friction forces are too low to set the ring into rotation.

The purpose of this study was to determine the range of values for the ratio of the two main roll speeds at which the process can be performed properly. Since the speed of the main roll is not a reliable value, it was assumed that the parameter k, defined as the ratio of the infeed velocity V_1 to the peripheral (linear) velocity V_c of the main roll at the point of contact between the tool and the annular charge, would be tested:

$$k = \frac{V_1}{V_C} \quad (1)$$

where: V_1 – main roll infeed speed [mm/s];
V_C – linear velocity of the main roll at the point of contact with the ring [mm/s]:

$$V_c = \frac{D\pi n_1}{60} \quad (2)$$

where: n_1–rotional speed of the main roll [rev/min];
D_g – diameter of main roll [mm].

The tests were carried out experimentally and theoretically using the same process parameters in both methods. Ring-shaped charges with initial dimensions of ø110×ø50×15 mm made of C45 grade steel (1.0503) with the chemical composition shown in Table 1 were used. A commercial D51Y-160E rolling mill (Fig. 2a) was used in the experiment, in which the main roller is driven and performs rotational motion about its axis and linear motion toward the mandrel, while the mandrel is undriven, performing only passive rotational motion about its axis. The beginning of the process with a hot charge placed in the rolling slot is shown in Figure 2b.

During the tests, tools with rectangular blanks (technological undercuts) limiting the axial movement of the shaped charge were used, the diagram of which is shown in Figure 3. The rolling process was carried out until the ring thickness reached 14 mm, i.e. the infeed motion of the main roller stopped when the working surfaces of the tools approached the distance of 14 mm. The rotational motion of the main roll was continued until the thickness of the ring was constant around the circumference. Only the right calibration roll was used in the process, which was the support point for the ring during the test run. The workpiece was heated to 1100 °C before rolling. It was assumed that the tests would be carried out for a infeed speed V_1 of the main roll in the range of 10–40 mm/s with a step of 10 mm/s. For each speed V_1, the speed n_1 of the main roll (thus the speed V_c) was decreased until slippage occurred

Table 1. Chemical composition of C45 (1.0503) grade steel [% wt]

C	Mn	Si	P	S	Cr	Ni	Mo	W	V	Al	Cu
0.42–0.5	0.5–0.8	0.1–0.4	max 0.04	max 0.04	max 0.3	max 0.3	max 0.1	-	-	-	max 0.3

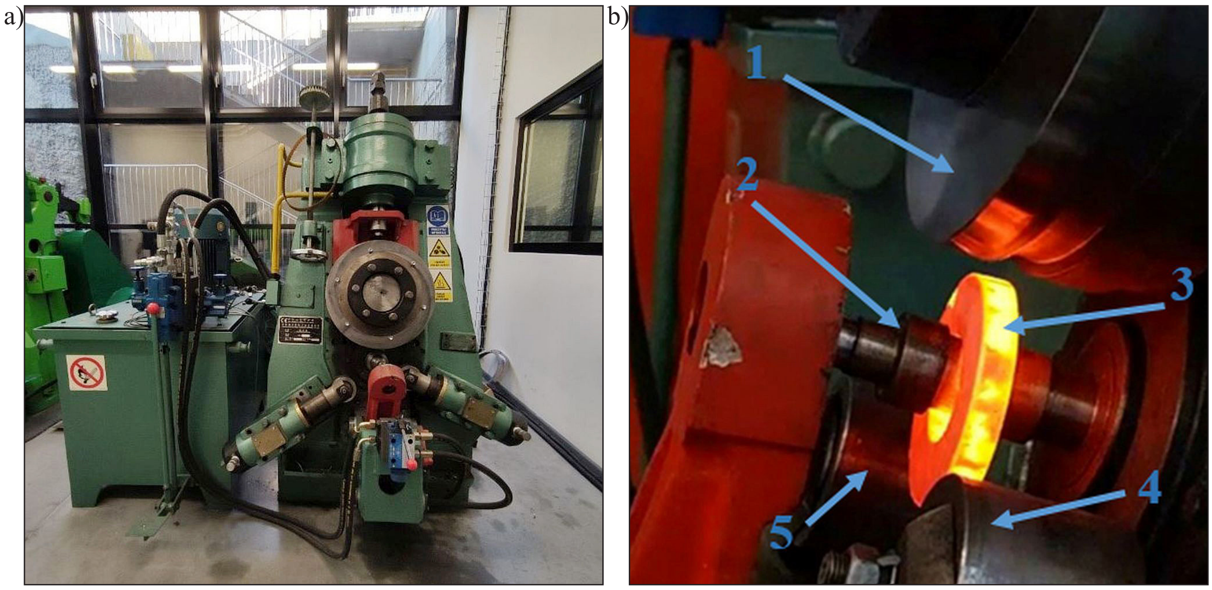

Fig. 2. D51Y-160E rolling mill used in experiments (a) and the initial stage of the rolling proces (b); 1 – main roll, 2 – mandrel, 3 – ring, 4 – right calibration roll, 5 – left calibration roll

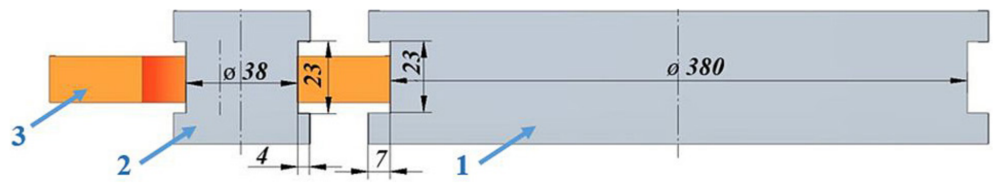

Fig. 3. Schematic of the tool geometry used in the study; 1 – main roll, 2 – mandrel, 3 – ring

Table 2. Parameters used in numerical simulations of the proces

Parameter	Value	Unit
Infeed speed of main roll	10 / 20 / 30 / 40	mm/s
Rotational speed of main roller	10–92	rev./min
Ambient temperature	20	°C
Tool temperature	150	°C
Workpece temperature	1100	°C
Heat transfer coefficient for steel C45	11000	W/(mm^{2}K)
Ambient heat transfer coefficient	20	W/(mm^{2}K)
Friction factor between the tools and the tools (shear friction model)	0.74	-

and a defective forging was obtained. The last test at which a correct ring was obtained was taken as the limiting speed ratio (factor *k*). In the experimental study, a special measurement system [19] was used consisting of: MOP encoders to study the angular displacement of the main roll and the mandrel, WDS path sensor to study the main roll's infeed path, WIKA pressure sensors to study the pressure in the system. The developed system is based on USB-6008 measurement card programmed in LabVIEW environment.

Theoretical tests were carried out with the parameters shown in Table 2 using the Forge NxT 1.1 program designed for the analysis of metal forming processes. The material model of C45 steel was taken from the program library.

RESULTS AND DISCUSSION

Based on the tests, it was found that when the infeed speed V_1 of the main roll was too high

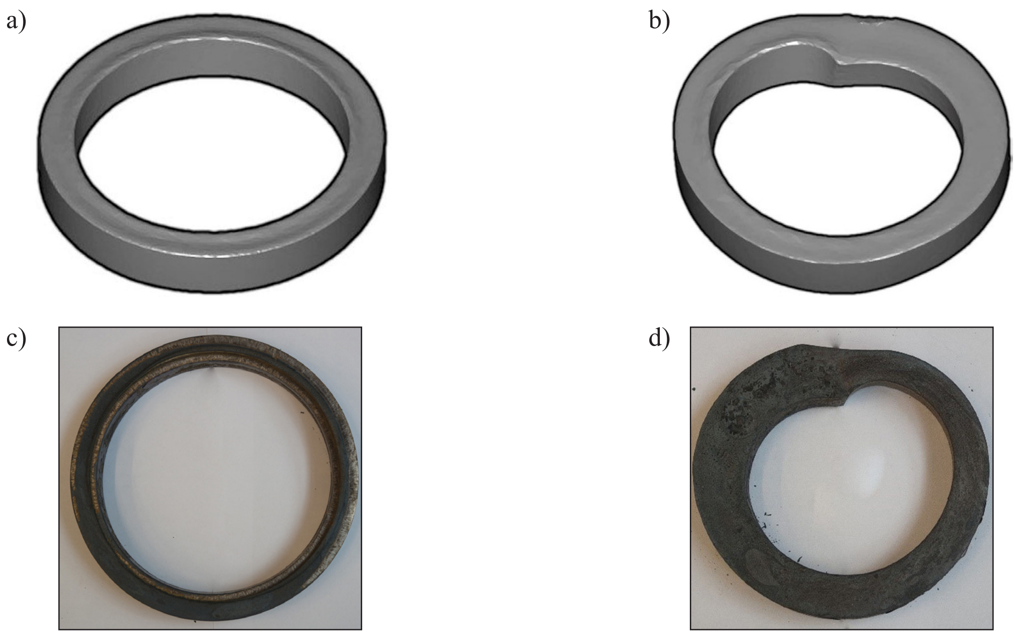

Fig. 4. Rings obtained in the study: a) theoretical values at the limiting value of the coefficient k, b) theoretical values with k greater than the limiting value, c) experimental tests at the limiting value of the k, d) theoretical values with k greater than

in relation to its rotational speed n_1 and its dependent peripheral speed V_c, slippage occurred between the tool working surface and the rolled ring. Consequently, the rolling process was not carried out to completion and a defective forging was obtained. With the correct velocity relationship V_1 and V_c (correct value of k factor), slippage did not occur and the product was correct. Fig. 4 shows the comparison of experimental and theoretical results. As can be seen, qualitative agreement on the shape of the forgings was obtained in both methods.

Table 3. Values of limiting speed ratio k – theoretical analysis

V_1 [mm/s]	V_c [mm/s]	k [-]
10	159.17	0.063
20	557.11	0.036
30	1094.32	0.027
40	1591.74	0.025

Table 4. Values of limiting speed ratio k – experimental study

V_1 [mm/s]	V_c [mm/s]	k [-]
10	397.94	0.025
20	795.87	0.025
30	1193.81	0.025
40	1591.74	0.025

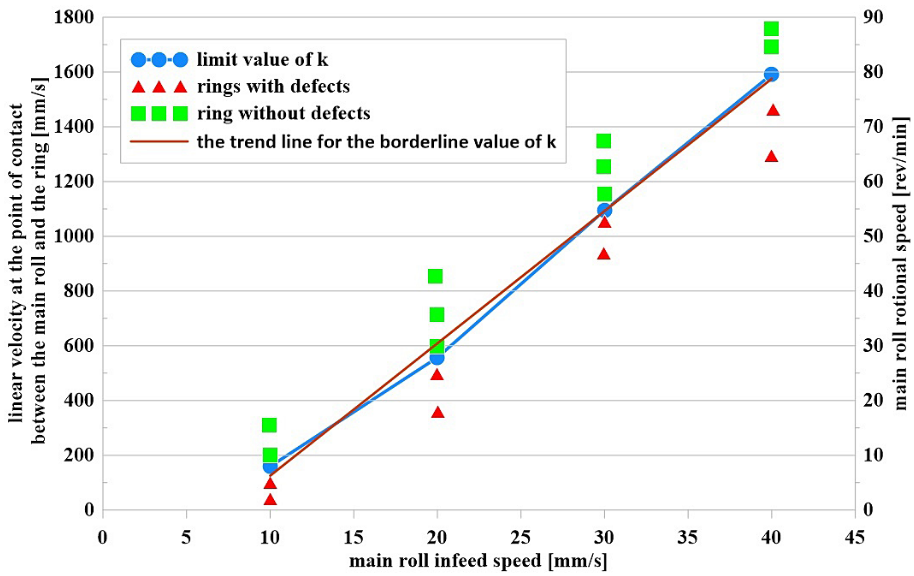

Fig. 5. Graph of maximum k-value – theoretical analysis

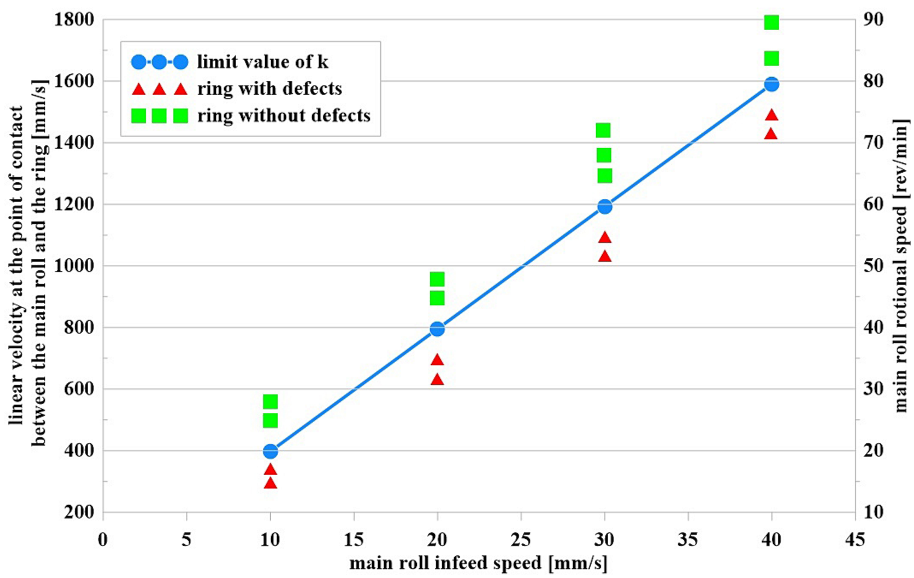

Fig. 6. Graph of maximum k-value – experimental study

Tables 3 and 4 show the determined values of the limiting *k*-factor and the velocities at which it was reached for the theoretical and experimental tests, respectively. For each infeed speed of the main roll, 4 or 5 simulations and experimental tests were performed. A graphical representation of these results is given in Figs. 5 and 6, where measurement points with smaller and larger values of the *k*-factor are additionally plotted in addition to the boundary results. It is worth noting that in the experimental study, the limiting ratio of the main roll's infeed speed to its peripheral speed is constant (k = 0.025). For numerical simulations for the range of higher tested velocities (V_1 = 30 mm/s and 40 mm/s), the limiting *k*-factor reaches similar values (k = 0.027 and 0.025, respectively), but for lower velocities its value deviates from the experimentally determined ones. For V_1 = 20 mm/s, it is 1.44 times larger, and for V_1 = 10 mm/s, it is 2.52 times larger than the experimental value. Thus, in the low velocity range, the numerical simulations show a stable process (no slip) even for velocity conditions well above the values at which slip occurred in the experiment.

CONCLUSIONS

This paper presents a study of the effect of the reciprocal relationship of the infeed speed to the peripheral speed of the main roll on the occurrence of slip in the radial ring rolling process. Based on the results obtained, the following conclusions can be made.

1. The ratio of the infeed speed to the peripheral speed of the main roll is essential for radial ring rolling. If the roll infeed speed is too high, slippage occurs and a defective product is obtained.
2. For the investigated range of parameters the limiting infeed ratio of the infeed speed to the peripheral speed of the main roll determined experimentally is k=0.025. For smaller values of the *k*-ratio the process runs properly, while for larger values slippage occurs.
3. The limit values of the *k*-factor determined from the numerical simulations have convergent values only for the larger range of velocities tested; for the smaller ones there are large differences. The reason for these discrepancies may be a reduction in the temperature of the rolled material at lower speeds, resulting in a change in the friction conditions between the tools and the ring. It seems reasonable to develop and use in simulations a friction model that takes into account the dependence of the friction factor on the temperature conditions of the process.

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