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Study of Cross Wedge Rolling Process of BA3002-type Railway Axle

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ABSTRACT

The paper deals with the concept of solid railway axle rolling using tools (rolls) in which the forming zones of individual workpiece steps are separated. Two types of tools were analysed, which were characterised by flat (typical solution) and convex (novel solution) forming surfaces of the wedge. Using the software Forge® NxT, simulations were performed of the rolling processes of the rail axle. Distributions of temperature, damage function, effective strain as well as force and torque courses were analysed. The results showed that it is possible to produce solid railway axles using the CWR method and confirmed the use of tools with a convex forming surface.

Keywords: cross wedge Rolling, railway axle, FEM.

INTRODUCTION

Railway axles are large-size products (weighing more than 400 kg) that are manufactured in large series. Currently, the main techniques used to manufacture axles are open die forging and forging on swaging machines [1]. Simultaneously with the development of the technologies used so far, work is underway to develop new methods of manufacturing these products, characterised by lower material and energy consumption. Cross wedge rolling (CWR) is considered to be one of such new methods [2].

The main problem in the CWR process of railway axles is the size of the tools. It is assumed that the length of the flat wedge tool will be approximately 6 m. This means that the diameter of the wedge rolls can be up to 2 m. In order to reduce the size of the tools, the use of parallel rolling was considered, during which the axle is formed simultaneously by 3 pairs of wedges. Using this solution, Pater et al. [3] reduced the nominal diameter of the rolls to 1.6 m, but the torque required to form the axle was as high as 1.4 MNm. However, it is not the very high torque that is the main problem of parallel rolling. As Bulzak [4] has shown, it is the much greater tendency to material cracking in the axial zone of the workpiece. In order to reduce this tendency, it has been proposed to roll in two operations [3] and to use an undercut in the sizing surface of the wedges, significantly reducing the number of deformation cycles [5]. In the reference literature, studies can also be found on the rolling of hollow axles, carried out both with [6] and without the use of a mandrel [7]. These processes also used parallel rolling, during which up to five pairs of wedges were used simultaneously. However, rolling trials, performed on a 1:5 scale by Peng et al. [8], showed that axles made in this way had many shape defects. Therefore, it was finally proposed that the centre step of the railway axle should be rolled by one pair of wedges, as is the case with solid axles.

This paper presents the latest concept of CWR of railway axles developed at the Lublin University of Technology. It assumes the use of wedge rolls with a nominal diameter of 1.8 m. The use of these tools significantly reduces torque by separating the formation of the central step from that of the side steps. Furthermore, it has been demonstrated that it is advantageous to use modified tools that are characterised by a convex wedge surface.

SCOPE OF THE ANALYSIS

The CWR process of the railway axle type BA3002, according to the EN1326 standard, was analysed. Figure 1 shows the axle as it was formed with a machining allowance of 5 mm. The assumption is that the diameter of the billet is equal to the largest diameter of the axle, which is 216 mm.

The next Figure 2 shows the wedge tool used to roll the selected railway axle. During rolling, two identical tools are used, which are fixed on 1400 mm diameter rolls. The distance between the axes of the cooperating rolls is 1800 mm. The tool is equipped with three wedges. The first of them (characterised by angles α = 15° and β = 33°) is placed centrally, while the other two (characterised by α = 22° and β = 11°) are symmetrically with respect to each other on the sides of the tool. In addition, the tool is equipped with two guide paths for the correct positioning of the billet and

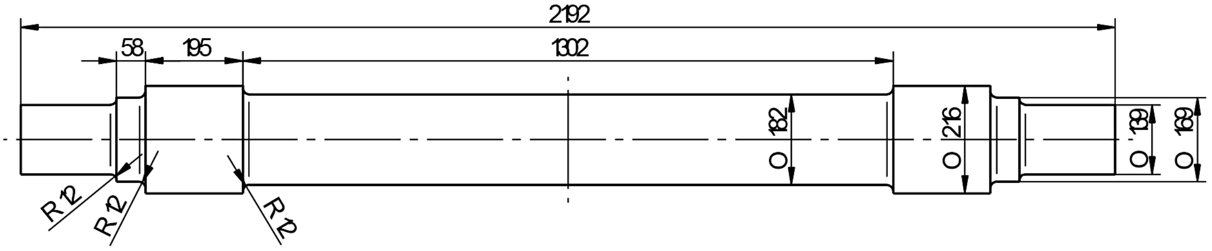

Fig. 1. The BA3002-type railway axle (according to the EN1326 standard) with machining allowances

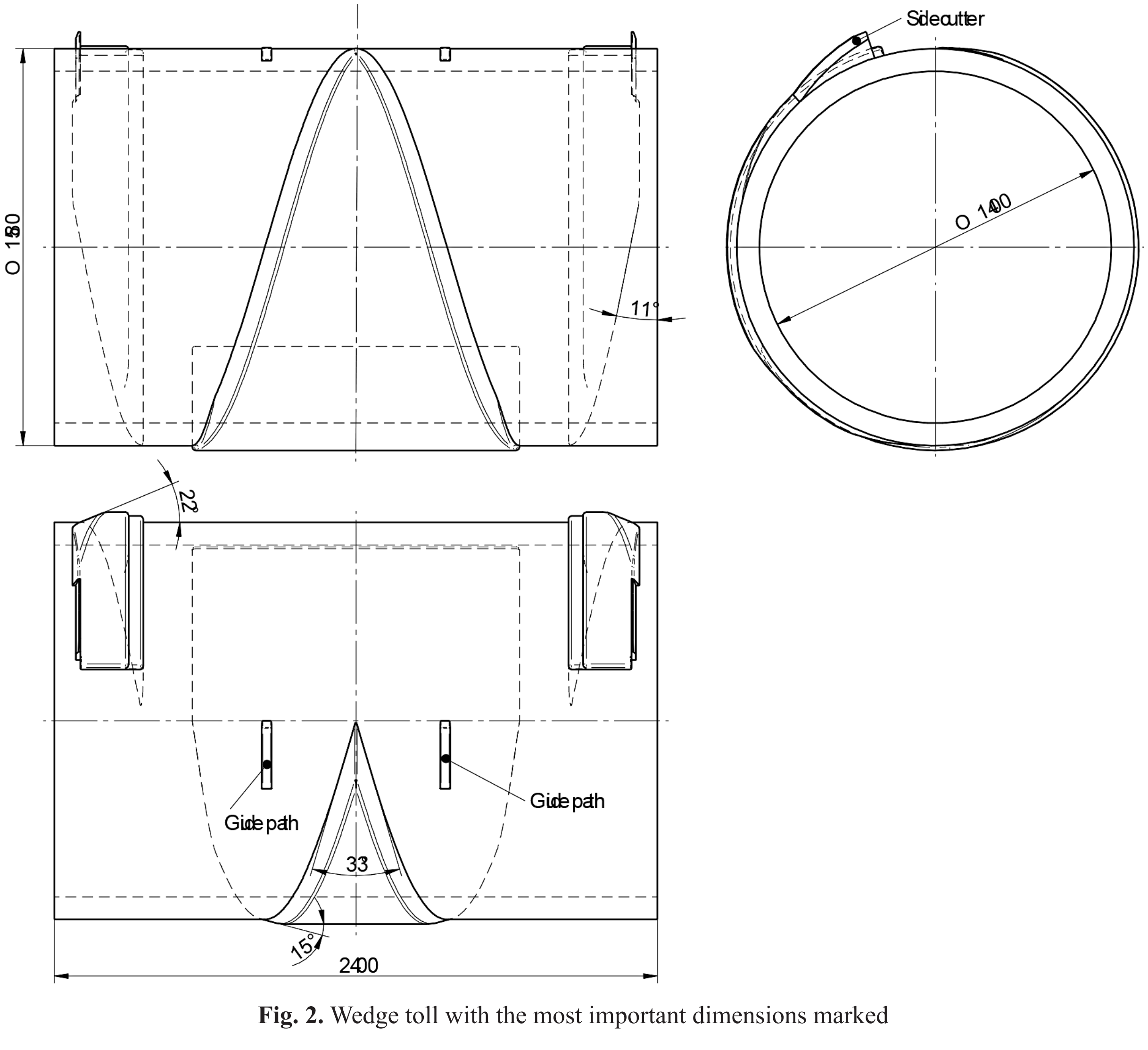

Fig. 2. Wedge toll with the most important dimensions marked

with two side cutters, which in turn are used to cut off the waste material.

Two rolling cases were considered. In the first case, typical tools, shown in Figure 2, were used. In the second case, novel tools were used, which had a convex forming surface, reaching tangentially to the sizing surface of the wedge. The differences between the outlines of the forming surfaces in both studied rolling cases are shown schematically in Figure 3. The new wedge shape is the result of optimisation performed by the author [9], which indicated that the use of tools with a convex forming surface is beneficial in terms of uniformity of pressures on the workpiece – tool contact surface. At the same time, it should be noted that the new wedge shape does not cause any difficulty when making tools, as they are currently milled on CNC machines.

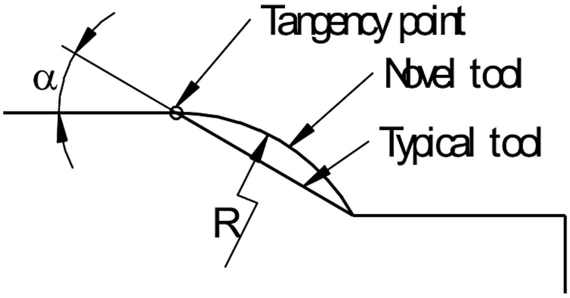

Fig. 3. Wedge shapes used in the analysis of the CWR process of a railway axle

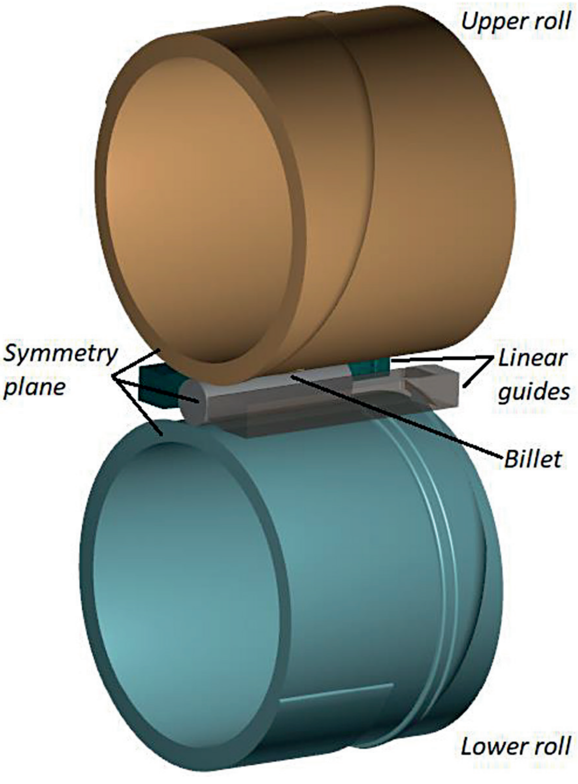

Fig. 4. Geometric model of CWR process of a railway axle using forming symmetry

Numerical simulations were performed using the Forge® NxT programme. This program has been used many times in the past in the analysis of cross and skew rolling processes [10–16], and the results of the simulations were in good agreement with the results of experimental studies.

Figure 4 shows a geometric model of the CWR process of a railway axle, taking into account the symmetry of forming. The model consists of two identical rolls (described earlier), two identical guide plates and a billet. The tools are modelled as perfectly rigid bodies, while the billet (workpiece) is modelled as a plastically deformable body. It is assumed in the simulation that the billet of dimensions Ø216×1650 mm is made of 42CrMo4 steel. The material model of this steel is described by the equation

$$\sigma_p = 1827.07\, e^{-0.00289T}\, \varepsilon^{-0.1123} \cdot \cdot\, e^{-0.4879/\varepsilon}\, \dot{\varepsilon}^{\,0.14368} \tag{1}$$

where: σ_p – flow stress, MPa; T – temperature, °C; ε – effective strain, -; $\dot{\varepsilon}$ –a strain rate, s^{-1}.

It is assumed that: the billet is heated to 1240 °C before forming, the rolls have a temperature of 250 °C and the guides have a temperature of 350 °C.The heat transfer between the tools and the workpiece is defined by a heat transfer coefficient of 10 kW/m^{2}K. The friction on the contact surface is described by the Tresca model and a friction coefficient of 0.9. The kinematics of the process is determined by the rotational speed of the rolls of 1.5 rpm.

RESULTS

The application of the FEM allowed the precise tracing of the formation of the railway axles, which for both analysed cases is shown in Figure 5. From this figure it can be seen that first the central wedge forms the middle step. Subsequently, the side wedges roll the remaining steps with smaller diameters. In the final stage of the process, the side cutters cut off the waste material. The railway axle obtains the intended shape and the type of tools used (typical or novel) has no noticeable effect on the forming process.

Due to the low rotational speed of the rolls (1.5 rpm), the axle forming process takes 40 s. However, such a long time does not cause the temperature to drop below the value recommended for hot rolling. This is evidenced by the temperature distributions in the rolled axles, shown in Figure 6. The material in the near-surface layers, where contact with cooler tools took place, has the lowest temperature. However, in the axial zone of the workpiece, the material temperature is close to the billet temperature. This favourable temperature distribution is due to both the high heat capacity of the workpiece and the conversion of plastic deformation work into heat. As far as the influence of the type of tools used on the temperature distribution is concerned, it is negligible.

The next Figure 7 shows the effective strain distributions in the railway axles rolled off with typical and novel tools. These distributions are very similar and typical of cross rolling processes. The strain is distributed in layers and takes the highest values on the outer surfaces, where frictional forces act to cause the material to flow in the circumferential direction. Slightly smaller strains occur in the axial zone of the part rolled by the novel tools.

One of the limitations of the CWR process is the formation of internal cracks in the axial zone of the workpiece. Figure 8 shows the distribution

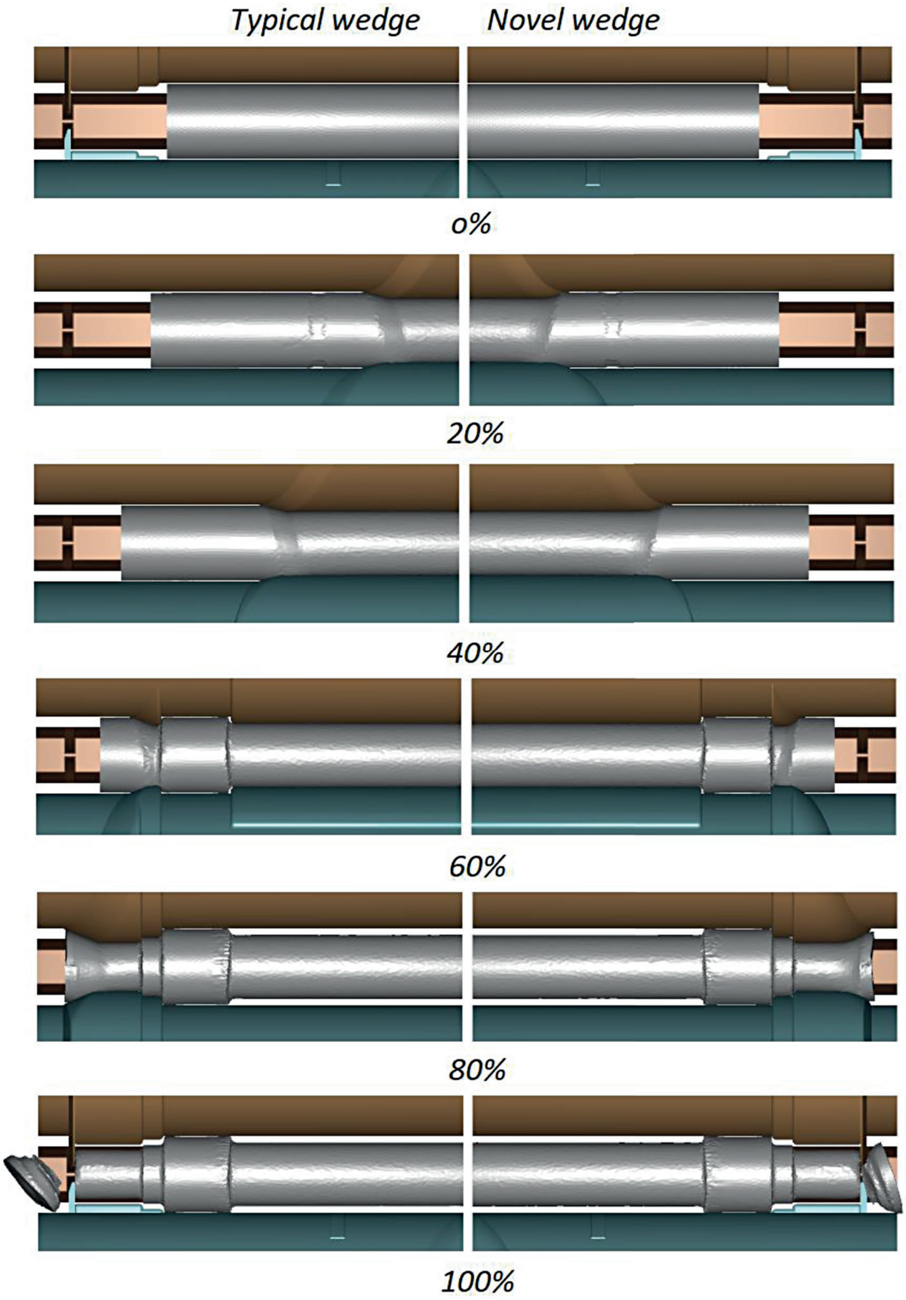

Fig. 5. Numerically simulated rolling process of BA3002-type railway axle

of the damage function calculated according to the Cockcroft-Latham criterion. The highest values of this function are found on the frontal surfaces where the material was cut as a result of the action of the side cutters. In the centre of the workpiece, however, the maximum value of the damage function is less than 1.4. At this point the material has a temperature of approx. 1200 °C (see Fig. 6). The critical damage value at which material cracking occurs for 42CrMo4 steel formed at 1200 °C is 3.55 [17]. Therefore, it can be concluded that in both analysed rolling cases, material cracking will not occur in the axial zone of the workpiece.

Figure 9 shows the radial force distributions during the CWR process of the railway axle. The highest forces occur at the final stage of forming the central step, when the rolling of the outermost steps additionally starts. The maximum force value is 4048 kN for a typical tool and 3830 kN for a novel tool. This means that the maximum force in the typical process is 5.7% higher than in the novel one. If we compare the average values of the radial force, this difference

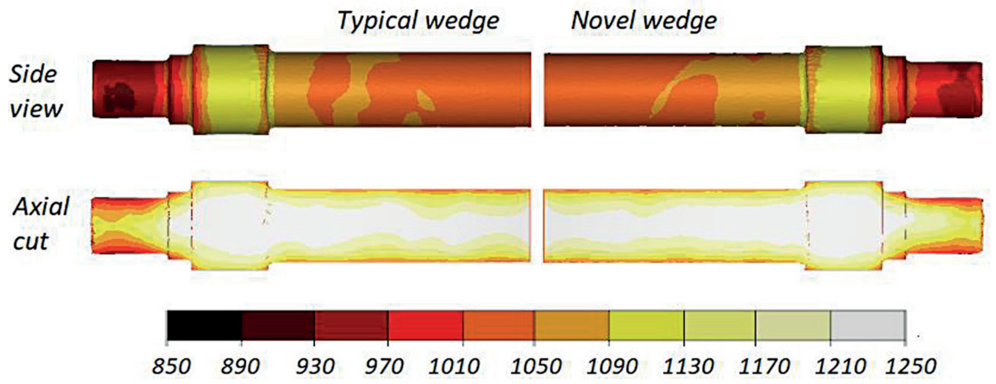

Fig. 6. Temperature distribution (in °C) in railway axles manufactured in CWR process

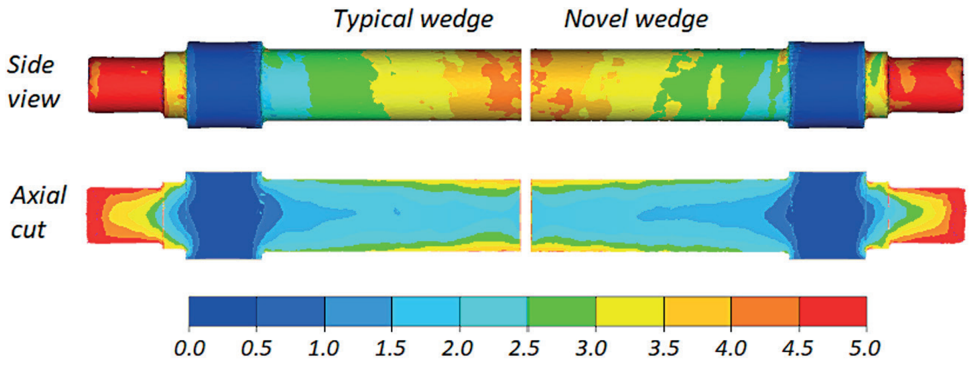

Fig. 7. Effective strain distribution in railway axles manufactured in CWR process

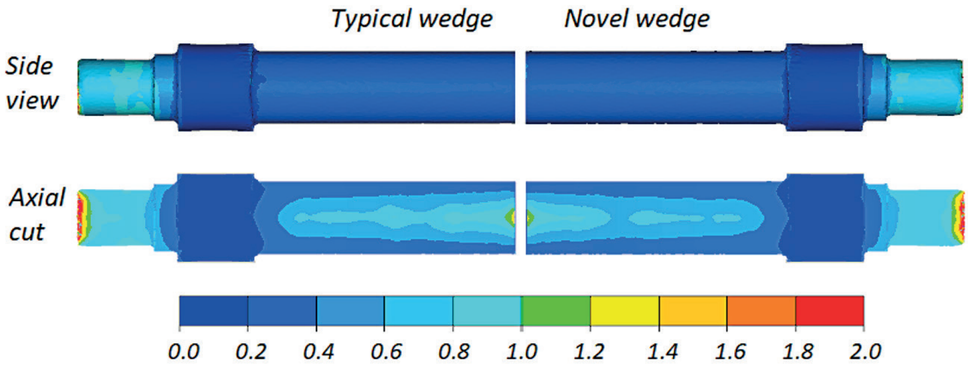

Fig. 8. Distribution of the damage function (according to the Cockcroft-Latham criterion) in railway axles manufactured in CWR process

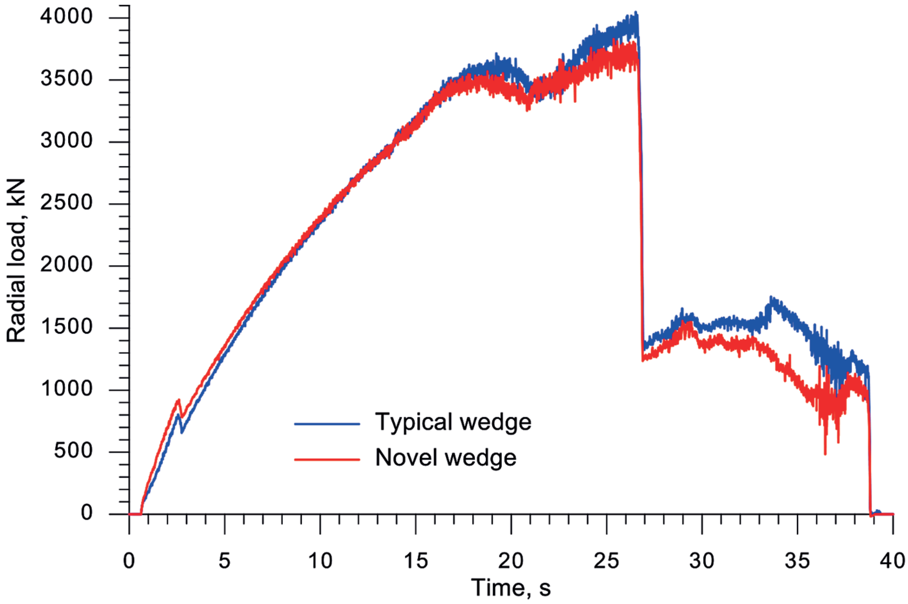

Fig. 9. Curves of the radial force acting on the roller in the analysed CWR processes of the railway axle

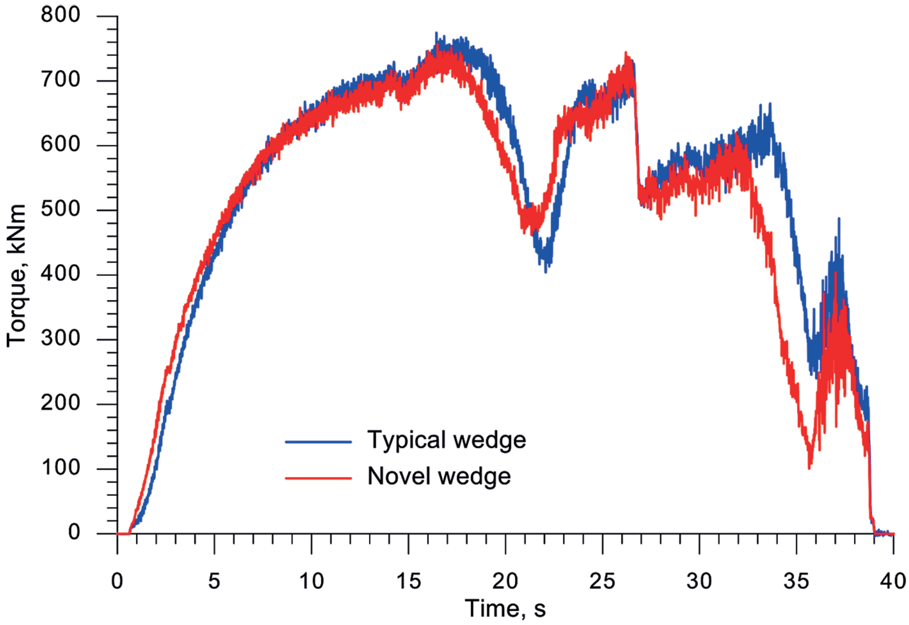

Fig. 10. Torque curves on the roller in the analysed CWR processes of the railway axle

decreases to 4.4%. Thus, we can conclude that the use of novel tools in the CWR process is beneficial.

The following Figure 10 shows the torque distributions determined numerically for the railway axle rolling cases analysed. The maximum torque value for a typical tool is 774.6 kNm and is 2.3% higher than the maximum torque noted for a novel tool (757.2 kNm). If the average torque value over the whole forming cycle is taken into account, it is 508.9 kNm and 585.5 kNm for the typical tool and the novel tool, respectively. The resulting energy required to forming of the axle is 6392 kJ for a typical tool and 6098 kJ for a novel tool. This means that the energy consumption of the typical process is 4.8% higher than that of the CWR process using novel tools.

Taking into account the maximum torque value and the rotational speed of the rolls, the power of the rolling mill can be determined. Assuming a power surplus of approx. 50%, it can be assumed that a rolling mill for the forming of railway axles could be driven by two DC motors of 175 kW each.

CONCLUSIONS

Based on the numerical analysis performed, the following conclusions are drawn:

1. Solid railway axles can be efficiently produced by cross wedge rolling (CWR).
2. By separating the individual axle steps during forming, the torque on the roll can be reduced to an acceptable value of less than 800 kNm.
3. The use of a low rolls rotational speed (1.5 rpm) does not result in excessive drops in the material being formed.
4. The CWR process of the railway axle should not result in the formation of internal cracks.
5. The use of tools with a convex forming surface in the CWR process of railway axles is beneficial as it reduces both the forming loads and the energy consumption of the manufacturing process.

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