

## NUMERICAL ANALYSIS OF SPLITTING WITHOUT WASTE BASED ON CROSS-WEDGE ROLLING IN DOUBLE ROLLING MECHANISM

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### ABSTRACT

The article presents the results of numerical analysis of splitting without waste on the basis of cross wedge rolling in double rolling mechanism. The analysed process concerns rolling the charge of V-shaped groove, and rotary bending causing the split of the material. In the calculations a method of finite elements (FEM) was used. The obtained results allowed detailed analysis of the splitting process in terms of the level of deformation, strains, material breaking, flow kinematics and strength parameters.

**Key words:** splitting without waste, cross wedge rolling, FEM.

### INTRODUCTION

Semi-finished products from smelting materials are most frequently used materials in industrial plants dealing with metal processing. This group includes widely used bars of circular cross section offered at the lengths of 3–6 metres. In industrial conditions the first operation is cutting with specialist tools. Considering the material costs, as a significant price-determining factor of the final product there is a large demand for a technology of splitting such materials in a waste-less manner. Companies look for technologies that offer short operation time with good quality of the splitting surfaces, especially the perpendicularity of splitting to the input material.

Specialist literature presents a few groups of methods of material splitting without waste. The most common methods are the ones based on sheering, such as cutting with cutting machines and the devices with specialist blankholders [3, 8]. The use of the above methods is burdened with drawbacks concerning low precision of cuts and lack of perpendicularity of head surfaces to the material axes [1]. Another group of methods realising the process of splitting without waste are the methods using the process of cracking. This

group includes a new author's method of splitting without waste based on cross wedge rolling. It concerns rolling the notch at the perimeter of the material and then rotary bend leading to the splitting break. The process is realised with flat segments (Fig. 1) and was positively verified in the previously completed research for the input in a form of full bars made of steel and copper and titanium alloys.

The basic parameters of the tools are: forming angle  $\alpha$ , bending angle  $\theta$  and absolute stamp  $\Delta r$  (Fig. 2). Detailed results of research in this range were presented in articles [4–7]. With regards to the requirements of the industry concerning effectiveness and the ease of automation process of splitting it is justified to make the analysis of splitting process based on cross wedge rolling with the use of rolling segments in double rolling mechanism.

### MAIN ASSUMPTIONS OF THE THEORETICAL ANALYSIS OF SPLITTING IN DOUBLE ROLLING MECHANISM

For the purposes of theoretical analysis of the process of splitting without waste on the basis of cross wedge rolling with double rolling mecha-

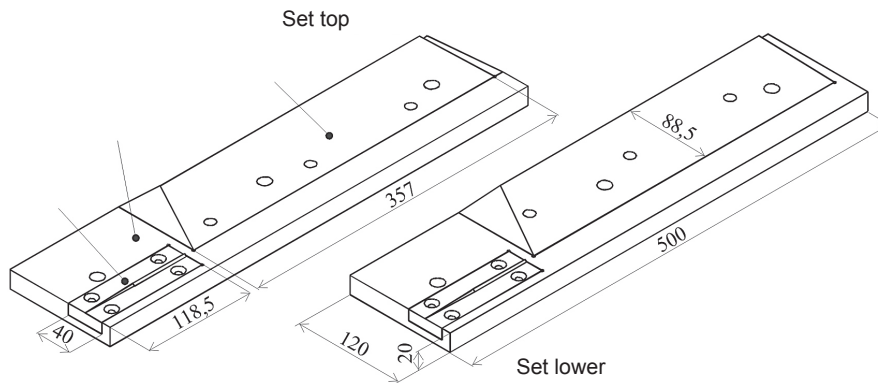


Fig. 1. The scheme of flat segments used in research [5]

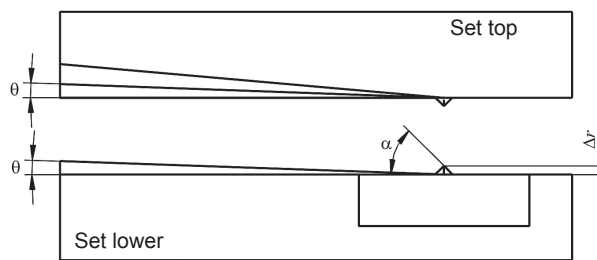


Fig. 2. A set of tools used in splitting without waste with marked main parameters of the process [5]

nism numerical simulations in the environment of Simufact software based on the method of finite elements was conducted. The calculations were made with the assumption of spatial deformation using thermo-mechanical model of processing. It was assumed that the temperature of input of tools equals the temperature of the environment, i.e. 20 °C. For the purpose of the analysis it was assumed that the material made of steel C 45 with a material model is contained in the programme library. The conditions of friction between the input and the tools were characterised in the model of permanent fracture, assuming that the fracture index is constant in the process and equals  $m = 1$ . The components of geometric model of the process include the tools in a form of two rolls, with the diameter of 400 mm with the surface shaping the notch and the part causing rotary bend of the splitting element and two trucks stabilising the location of the semi-finished product during the process (Fig. 3). The input is a bar with diameter of  $D = 30$  mm. For the analysis a perfectly stiff model of tool material was used and tool edge rounding was neglected. The calculations were made for a forming angle  $\alpha = 45^\circ$ , bending angle  $\theta = 3^\circ$  and absolute stamp  $\Delta r = 5$ . The value of geometric parameters of tools were developed on the basis of the results obtained for the set of flat tools and most frequent industrial tools phased at the angle of  $45^\circ$ .

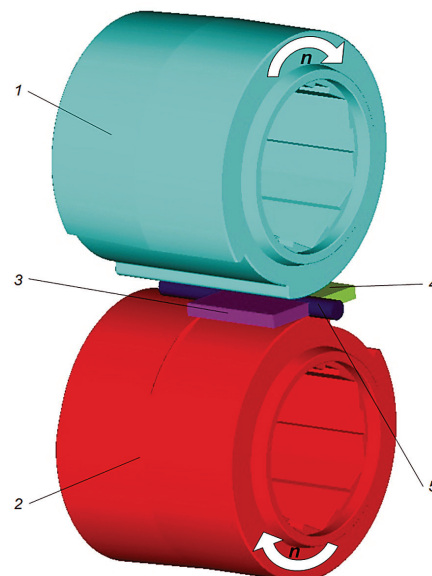
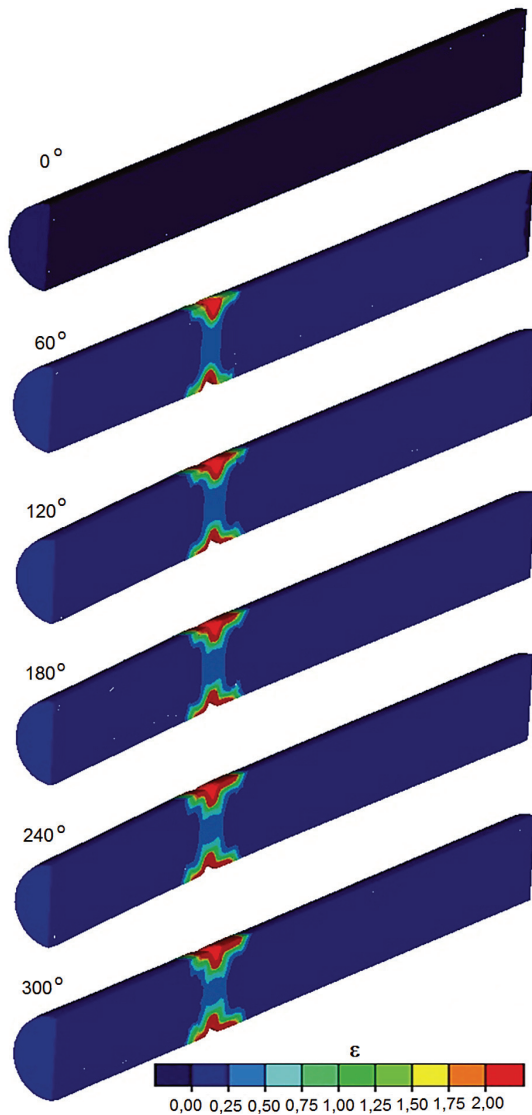


Fig. 3. Geometric model of splitting without waste with cylindrical tools: 1 – upper roller, 2 – lower roller, 3, 4 – track, 5 – semi-finished product

## RESULTS OD TEORETICAL ANALYSIS

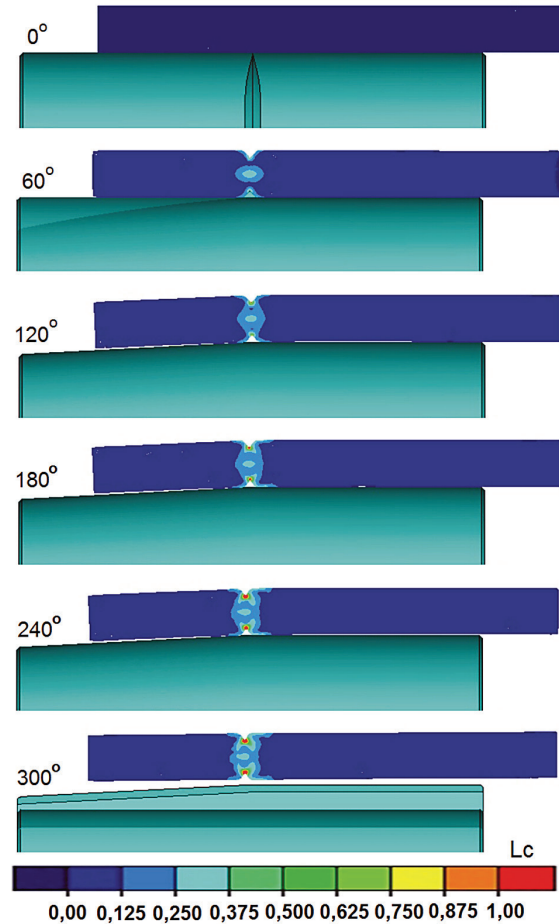
On the basis of the conducted numerical calculations, the results presenting the stages of process regarding tools' rotation angle in the range  $0^\circ$  do  $300^\circ$ . It is the range of rotation including the working elements of the splitting system. Figure 4 presents the distribution of intensity of deformations in the cross-section of the split bar.



**Fig. 4.** Distribution of deformation intensity calculated in FEM simulations of splitting without waste, depending on angular position of tools

In the first stage of the process, concerning the deformation of a V-shaped groove, concentration of deformations in the narrowing area can be observed. In the subsequent stage, larger volume of the material is deformed, due to rotary bending. The intensity of deformation in this stage is also increasing. The results obtained for the double roller mechanism manifest resemblance to splitting with plat tools.

The numerical simulation also concerned the analysis of fracturing conditions on the basis of Cockroft-Latham energetic criterion, defined as fracturing criterion [2]. For the steel bar C45 the value of limit integral was assumed (according to the above criterion) defined with the moment of fracture initiation  $C_{gr} = 0.69$  [5]. Figure 5 presents the distribution of fracture

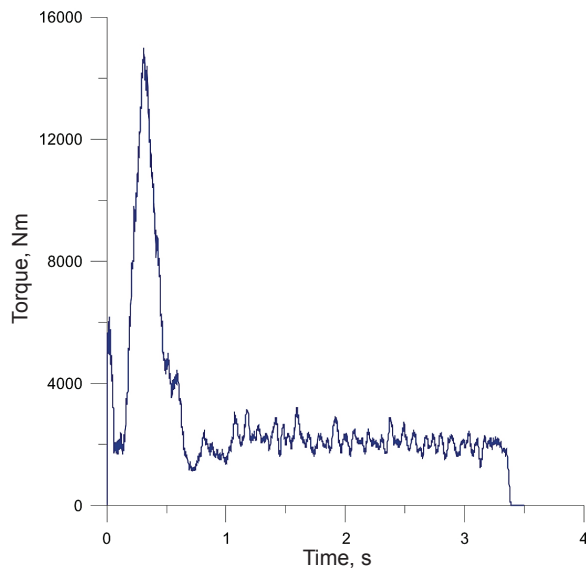


**Fig. 5.** Distribution of damage criterion according to Cockroft Latham calculated in FEM in the simulations of splitting without waste, depending on angular location of tools

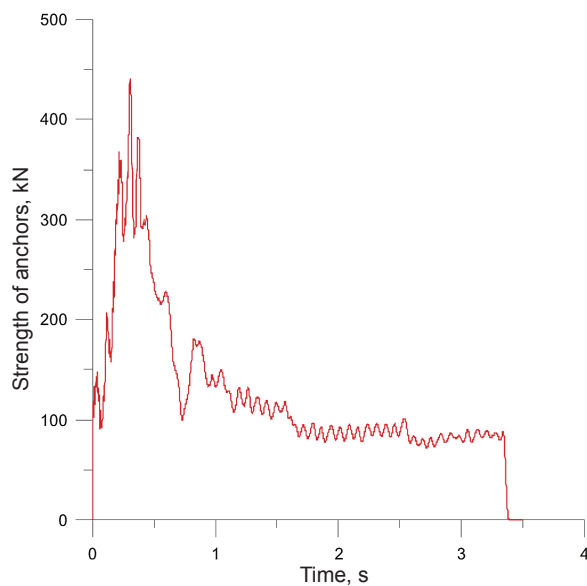
initiation in the cross section of the bar. As the analysis of the obtained distribution of values shows, the limit values are obtained as soon as after reaching of 180° the turn. Further turn of the tool generates the conditions necessary for splitting the material.

One of significant elements defining the possibilities of using the examined method in industrial conditions is defining the strength parameters of the process. On the basis of numerical analysis the values of rotation moment were defined in during the work of the tools (Fig. 6). The largest values of moment are recorded in the phase of ripping the splitting edge forming the notch. The phase of rotary bending generates that highest range of load at the level of 25% of the maximum value.

Another significant parameter is the value of spreading force (strength that works in perpendicular direction to the axis of rollers and lies on



**Fig. 6.** Rotary moment calculated in FEM methods on one of the rollers in the simulation of slitting without waste



**Fig. 7.** Spreading force marked with FEM in the simulations of splitting without waste

their surface). Maintaining the strength of the roller that ensures transformation of maximum values of spreading force is necessary for the stability of splitting process without waste. In the range of the obtained results, the course of the analysed force coincides with the value of rotary moment (Fig. 7). The largest values are recorded in the phase of forming the notch. The course of graph also manifests characteristic descend related to the advancement of material splitting.

## CONCLUSION

The results of theoretical tests optioned on the basis of numerical simulation FEM proved the possibility to use double roller mechanism for the realization of splitting steel C45 bars without waste.

Theoretical analysis of strain considering Cockroft-Latham damage criterion proved the existence of favourable conditions for splitting the examined material.

The results of force parameter calculations showed that the highest values of rotary moment and spreading force are recorded in the first phase of the process, i.e. forming the notch. Spreading force is significant for the selection of the machine that will realise the process. The use of rolling mill with too low body stiffness can influence on improper notch formation and decreasing the bending angle  $\theta$ , consequently, to decrease the efficiency of the process or disabling it.

The obtained results are coherent with the research results obtained with the use of flat tools for the process, what justifies the experiments of producing tools and making tests of splitting steel bars without waste with the use of double roller working mechanism.

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