

J. BARTNICKI*, J. TOMCZAK*, Z. PATER*

NUMERICAL ANALYSIS OF THE CROSS-WEDGE ROLLING PROCESS BY MEANS OF THREE TOOLS OF STEPPED SHAFTS FROM ALUMINUM ALLOY 7075

ANALIZA NUMERYCZNA PROCESU WALCOWANIA POPRZECZNO KLINOWEGO TRZEMA NARZĘDZIAMI STOPNIOWANYCH WAŁKÓW ZE STOPU ALUMINIUM 7075

This paper presents results of numerical calculations for the rolling process by means of three tools of stepped shafts from aluminum alloy 7075. Forming with the usage of tools with three different wedge spreading angles underwent analysis. In the paper, the obtained distributions of stresses, strains and Cockcroft-Latham damage criterion were given. Moreover, the influence of the wedge spreading angle on shape faults presence in the obtained product was determined. At the same time, the force parameters, which play a crucial role in the designed experiment, were analyzed.

Keywords: Cross – wedge rolling, FEM, stepped shafts

W artykule przedstawiono wyniki obliczeń numerycznych dla procesu walcowania trzema narzędziami wałków stopniowanych ze stopu aluminium 7075. Analizą objęto kształtowanie za pomocą narzędzi o trzech różnych kątach rozwarcia klina. W pracy podano uzyskane rozkłady naprężeń, odkształceń oraz kryterium pęknięcia wg całki Cockrofta – Lathama. Ponadto, określono wpływ kąta rozwarcia klina na powstawanie błędów kształtu w uzyskiwanym wyrobie. Równoległe przeanalizowano parametry siłowe, których wyznaczenie ma kluczową rolę w projektowanym eksperymencie.

1. Introduction

Stepped shafts (full and hollow) are applied in different branches of techniques on a large scale. The manufacturers of these products constantly search for new solutions guaranteeing faster work and reliability at the lowest cost per piece. In order to meet these requirements, it is necessary to look for new solutions, both at the designing stage and during manufacturing. Efficiency is very often the most important economical criterion, which, by no means, highlights the advantages of metal forming in comparison with machining process [1-4].

This paper presents the numerical analysis results of the stepped, hollow shaft manufacturing by means of cross wedge rolling technology. Presently, this method finds larger scope of applications in industrial conditions. It concerns mainly automotive and aviation branches and it is focused on manufacturing of hollow shafts and axles. This is caused by more and more restrictive norms and regulations concerning pollution and increase of transmissions systems characteristics.

2. Cross wedge rolling (CWR)

The main methods of this technology are presented in Figure 1. The wider applications are connected with two rolls and two flat tools solutions. Because of simplicity of tooling processes, the latest method is the cheapest in applications,

but in the case of hollow part forming the most interesting is solution with three rotating tools – wedges [1-4].

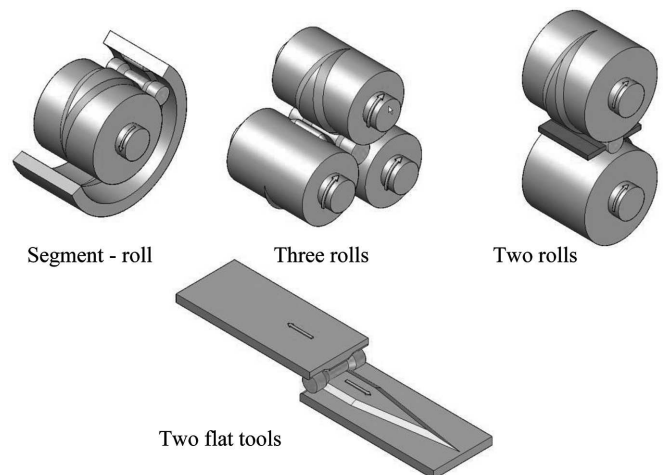


Fig. 1. Main CWR methods [1]

Due to this fact in the present paper the authors focused on calculations of lightweight hollow part from aluminium alloy 7075 forming by three tools method. More research in this field is described with details in works [5-8]. The CWR method with three tools assures more stable rolling conditions due to three zones contact between workpiece and tools. Hence, the

stability of this process can be disturbed by the different phenomena as: triangulation connected with slipping phenomenon presence or internal wall thickness disturbances in billet sections [2,6]. Processes impossible to realize applying two tools CWR method (with rolls or flat wedges) can be successfully finished by CWR process with three tools. This fact permits to propose this solution for manufacturing of stepped shaft with larger area reduction ratio, together with application of thinner tubes as billets [3].

3. Numerical analysis

Numerical calculations of the cross – wedge rolling process of hollow stepped shaft with three tools, realized with the application of software Simufact, according to the schema given in Figure 2, were discussed. In order to achieve the result the most similar to the real one, it was decided that the process would take place in conditions of heat exchange with the environment. Material model of aluminium7075 was taken from software library. The temperature of the billet was 460°C and the forming rolls (modelled as rigid bodies) was assumed 150°C. The heat exchange coefficient between tools and the billet was assumed equal 5000 W/m²K and between the billet and the environment it was 200 W/m²K. Constant friction model with friction factor $m = 1$ was taken into account during calculations.

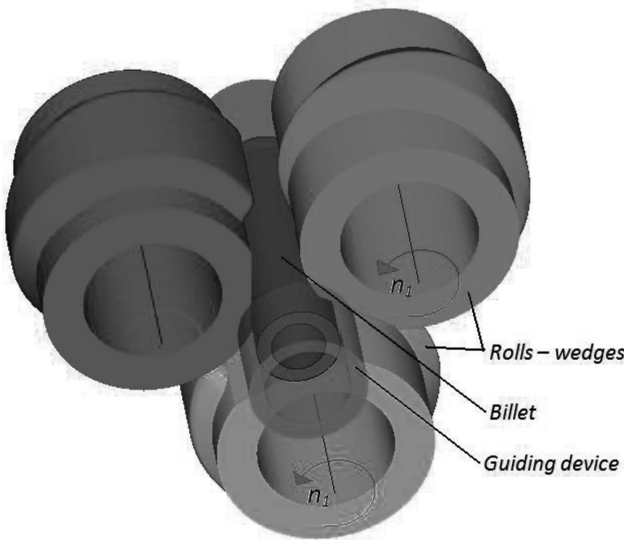


Fig. 2. The worked out for the calculations needs model of CWR process of the stepped hollow shaft forming

Tools rolls sets have the external diameter $\varnothing 215$ mm and constant forming angle $\alpha = 30^\circ$ [1]. For the calculations needs three different spreading angles β were used in designing and they have values: 9.0° ; 10.5° and 12.0° [1]. Tools rotary velocity n_1 was constant and set on $n_1 = 15$ rot/min. The only element that underwent deformation was the billet – tube with the external diameter $\varnothing 42.2$ mm and wall thickness $g = 7.3$ mm, other elements, such as rolls, were considered as rigid elements which did not undergo deformation. Compositions of the mentioned earlier technological parameters were taken into calculations. Figure 3 presents the next stages of the forming process with distributions of effective stresses with

process advancement given in percents. The maximum values of effective stresses during this process reach the values about 80 MPa at the area of contact tools – workpiece up to 80% of process. After that stage rolled part begins to be sized and stresses values decrease till the end of the rolling.

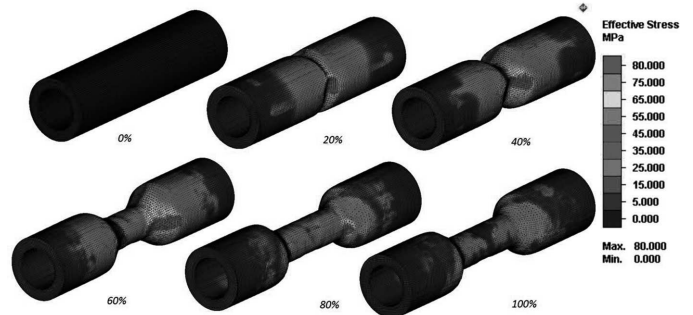


Fig. 3. The workpiece progression of shape during CWR process with the marked distributions of effective stresses with process advancement (tools with spreading angle $\beta = 9^\circ$)

For comparison of spreading angle β influence on the process course, the parallel calculations with different values of this very important technological parameter were realized. In the next figure (Figure 4) progression of part shape rolled by means of tools with spreading angle $\beta = 10.5^\circ$ is shown. What is more, in the same picture the distribution of temperature during process is presented.

Comparing the progression of formed necking in the middle of the part, it is visible that in the case of bigger spreading angle ($\beta = 10.5^\circ$) external surface is disturbed by spiral tracks. It is caused by too big spreading angle value, which is connected with too intensive axial flow of material. In the following rotations occurring tracks can not be removed. Regarding the temperature distribution during the process course, it can be stated that decrease of part temperature is not significant and the temperatures at the end of the process do not exceed the value lower than 400°C. The moment between 40%-60% of the process progression, when the temperatures are lower, is connected with the first contact of tools conical surfaces with the formed material. After that the temperature values increase.

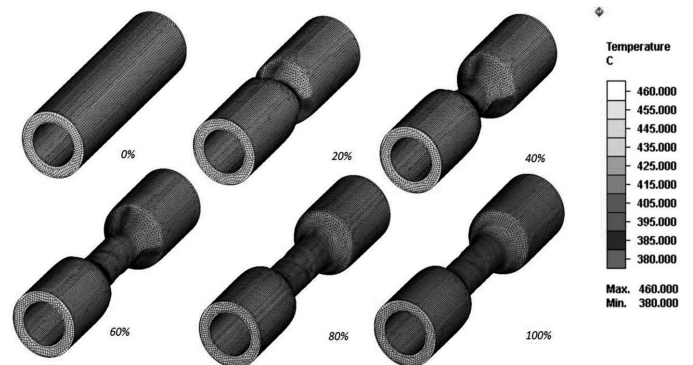


Fig. 4. The workpiece progression of shape during CWR process with the marked distributions of temperature during process advancement (tools with spreading angle $\beta = 10.5^\circ$)

The presence of spiral tracks on the surface of the rolled billet shows the risk of process stability disturbance. In this

case, it was connected with too fast cutting of material (with bigger β values) and increased risk of slipping phenomenon presence. In the CWR processes realized by means of three tools slipping problem causes fault shape effect in the particular form of triangulation. This phenomenon was well observed during the process realized with spreading angle $\beta = 12^\circ$, what is shown in Figure 5. The first symptoms of triangulation can be observed at the middle value of $\beta = 10.5^\circ$. The distribution of effective strains in part cross section begins to be non-circular, yet the obtained part is rolled with constant velocity. The further increase of β angle up to $\beta = 12^\circ$ results in intensive triangulation and slipping. This effect has also consequence in the wall thickness changes of final parts. Well visible homogeneous wall thickness distribution in longitudinal section of part rolled with $\beta = 9^\circ$ confirms stable process course with the mentioned parameters. With the increase of spreading angle β values this distribution become to be instable with the tendency to decrease the wall thickness of the part in the middle zone of the reduced diameter. All calculated cases were also compared within the scope of load parameters. The changes of radial forces acting on one roll are presented in Figure 6. The comparison of these forces courses also gives the response about process stability. At about 20-30% of process advancement it is possible to observe the increase of force oscillations. In the case of the stable process ($\beta = 9^\circ$), this phenomenon disappears and radial force values reach the stable level. In the cases of triangulations, the force levels increase due to rolled part circular shape changes. The time of rolling is also depended on tools shape. In the case of wedges with the smallest spreading angle $\beta = 9^\circ$, the process lasts longer due to the biggest working length of the wedge.

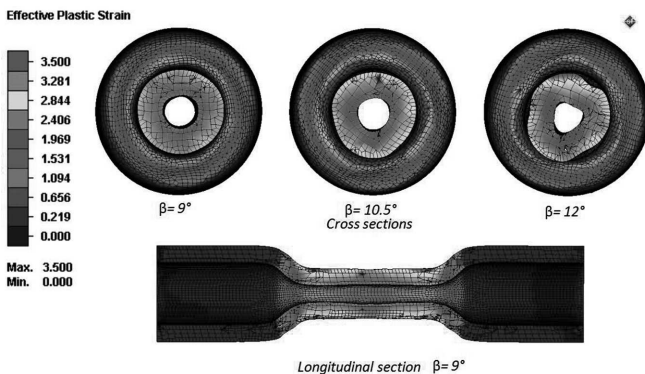


Fig. 5. The influence of spreading angle value β on the part shape in the cross sections (values of β marked) and wall thickness distribution in rolled part at $\beta = 9^\circ$

4. Summary

The conducted numerical calculations show the possibility of forming of stepped hollow parts from aluminium alloy 7075 by means of CWR with three tools. On the basis of the obtained numerical results, it was planned to make experiments in the rolling aggregate, allowing for practical realization of the CWR process by means of three wedges mounted on rolls.

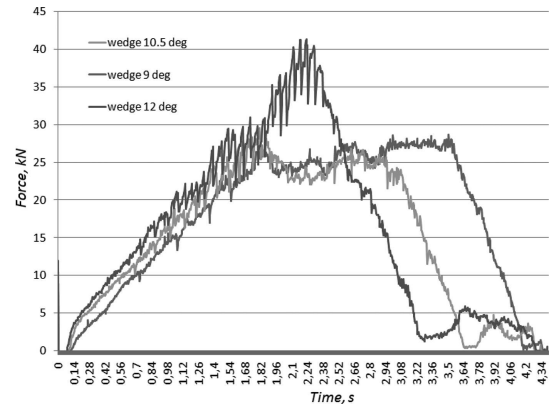


Fig. 6. The changes of radial force acting on the one roll depending on spreading angle value β

The further works on determining the dependency between the process parameters and the achieved dimensional deviations of the formed products should lead to obtain products of shape close to the final outline.

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