A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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A. TOFIL*

RESEARCH OF NEW SPLITTING PROCESS OF PIPE BILLETS FROM 2618A ALUMINIUM ALLOY BASING ON CROSS-WEDGE ROLLING

BADANIA NOWEGO PROCESU DZIELENIA BEZODPADOWEGO WSADÓW RUROWYCH ZE STOPU ALUMINIUM 2618A BAZUJĄCEGO NA TECHNOLOGII WALCOWANIA POPRZECZNO-KLINOWEGO

This paper are presented the results of theoretical and experimental research on splitting without waste of pipe billets from aluminium alloy realized basing on cross-wedge rolling method. The analyzed process is connected with rolling of a V-shape groove on a split billet circumference, and later with rotary bending causing material separation. In theoretical analysis, based on simulations by means of finite element method, basic models of metal cracking (brittle and ductile) were applied. During calculations, the following process parameters were changed: forming angle α, bending angle θ and reduction ratio Δr. The achieved results allowed for a precise analysis of the splitting process within the scope of: state of strain, kinematics of flow, force parameters, state of stresses and type of cracking of the split material. On the basis of experimental research, the influence of the analyzed parameters on the surface of splitting was estimated and scope of parameters guaranteeing the assumed quality of the product was given. The comparison of theoretical and experimental results showed good conformity.

Keywords: Splitting without waste, aluminium alloy

W opracowaniu przedstawiono wyniki badań teoretyczno-doświadczalnych dzielenia bezodpadowego w realizowanego w oparciu o metodę walcowania poprzeczno-klinowego. Analizowany proces polega na odwalcowaniu na obwodzie dzielonego wsadu rowka w kształcie litery V, a następnie przeginaniu obrotowym doprowadzającym do rozdzielenia materiału. W obliczeniach wykorzystano metodę elementów skończonych (MES). W analizie teoretycznej wykorzystano podstawowe modele pękania metali (kruchego i plastycznego). Podczas obliczeń zmieniano: kąt kształtujący α, kąt gięcia θ, gniot bezwzględny Δr oraz długość oddzielanego odcinka wsadu l. Uzyskane wyniki pozwoliły na dokładne przeanalizowanie procesu dzielenia w zakresie: stanu odkształcenia, kinematyki płynięcia, parametrów siłowych, stanu naprężenia oraz rodzaju pękania dzielonego materiału. Na podstawie badań doświadczalnych oceniono wpływ badanych parametrów na stan powierzchni rozdzielenia i wskazano zakres parametrów zapewniających założoną jakość wyrobu. Dokonano porównania rezultatów teoretycznych i doświadczalnych uzyskując dobrą zgodność.

1. Introduction

In recent years hollow products are gaining popularity in automotive and aviation industry. They allow to reduce the weight of a given product compared to the full one by up to several tens of per cent, while maintaining the ability to move the same load. For several years the research are carried out at the Lublin University of Technology into shaping of hollow forgings. The original technology developed in this center includes cross-wedge rolling [1], rolling extrusion [2], rotary compression [3] and forging on three-slides forging press [4]. In the above mentioned processes pipe billet are formed, which are obtained by cutting long pipes into smaller sections. The need to develop the technology which would allow to cut such materials without waste and provide a short time of operation while maintaining high quality of split surfaces was created.

The analysis of professional literature shows that there are several groups of cutting methods, in which no waste is produced. Traditional methods of splitting without waste use mainly shearing process. The group widely uses cutting shears and using instruments equipped with special clamps or allowing the initial incision of the notch [5]. These methods have drawbacks such as lack of precision in the length of the cut sections and the lack of front surfaces perpendicularity to the axis of the material and important factor affecting the quality of the surface of the splitting is process speed [6]. The second group of methods for without waste splitting of material is based on separation as a result of cracking. In some processes, splitting can be implemented with the use of the compression stress [7], vibration [8] and can be implemented with the use of the stress concentration caused by notch acting [9]. To this group belongs the method which analysis in relation to pipe billet from 2618A aluminium alloy is presented in this article.

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2. Characteristics of splitting process

The new innovative method is based on the technology of cross-wedge rolling. This method deals with notch rolling on the material circumference, and next on rotary bending leading to parting fracture. This process can be realized at the application of cylindrical (Fig. 1a) or flat (Fig. 1b) segments. The basic parameters of the tools are: forming angle α, bending angle θ and reduction ratio Δr (Fig. 2).

a) b)

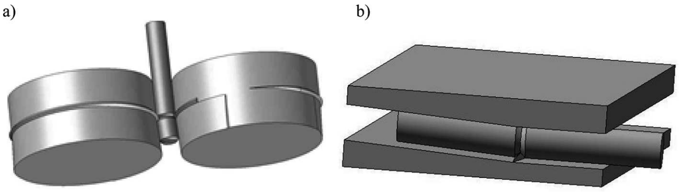

Fig. 1. Schema of splitting without waste process, basing on cross-wedge rolling with the application of: a) cylindrical segments, b) flat segments

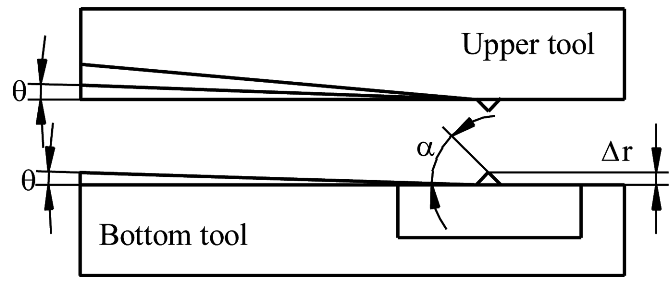

Fig. 2. Schema of tools with main parameters of the process

In previous research works this method has been positively verified for billets in the form of bars from steel and copper and aluminium alloys. The detailed results were described in works [10÷13]. Another stage of research presented pipe billets splitting from aluminium alloy 2618A. The research were carried out in two stages. The first included the numerical simulations to determine the influence of basic process parameters on the research course. In the second stage an experimental study was performed to verify the theoretical results.

3. Numerical simulations

3.1. The main assumptions of the theoretical analysis

Numerical simulations were carried in the Simufact environment based on the finite element method. Thermo-mechanical calculation model was considered with the assumption of three dimensional state of stress. It was assumed that that billet and tools temperature was the same as the environment temperature of 20°C. The material model was taken from the software library. Friction conditions between the billet and tools were characterized by constant friction model, assuming that friction factor was constant during the process and equal m =1. The model consists of two flat tools moving with velocity v =0,1 m/s, pipe billet of external diameter D =20 mm and internal diameters d =10 mm, 12 mm, 14 mm, 16 mm and 18 mm, and a holder that's sets the position of billet (Fig 3). In calculations, a rigid model of tools material was assumed, and rounding of tools edges was omitted. As changeable parameters the following were assumed: forming angle α (30°, 45°, 60°), bending angle θ (1°, 3°, 5°) and reduction ratio Δr (1 mm, 2 mm, 3 mm).

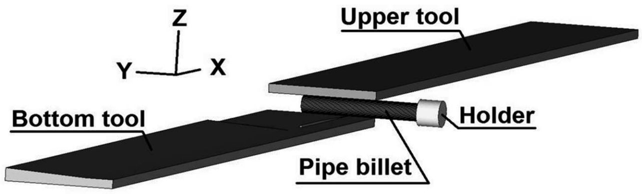

Fig. 3. Geometrical model of the process of splitting the billet pipe used in the FEM analysis

3.2. Results of theoretical analysis

The next stage of the process of splitting was shown on Fig. 4. In addition the effective plastic strain distribution on the surface of splitted billet pipe was given. In the first phase of the process, when the groove of V-shape is formed, strains concentrate mainly in the necking area. In the second stage of the process, due to rotary bending, material volume undergoing deformation increases, too. For all cases, given in Fig. 4 the process course and the strain distribution are of similar quality. There are only quantitative differences depending on process parameters. Enlarging of strains value in the splitting area is formed by the increased of bending angle θ and reduction ratio. The forming angle α does not show crucial influence on this parameter.

An important element of the theoretical study was to analyze the stress present in the cross section of the split. The purpose of this analysis was to determine the mechanism of cracking. It was assumed that for the analysis of the formation of plastic scrap the energy criterion of Cockroft-Lathaman was considered, and for the analysis of brittle cracking the hypothesis of de Saint Venant was considered.

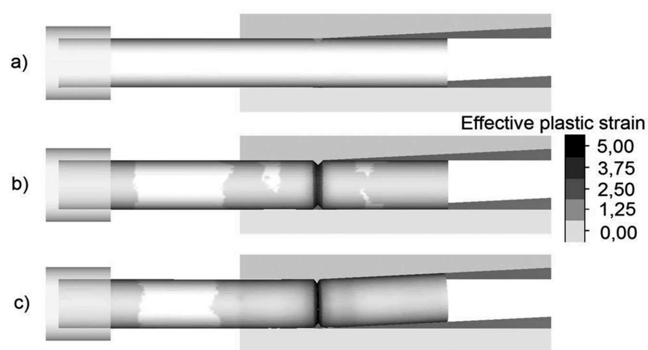

Fig. 4. The stages of splitting process with given strain distribution for pipe billet from 2618A alloy at: D =20 mm, d =14 mm α =45°, θ =3°: a) process beginning, b) end of groove forming stage, c) end of bending stage

The damage criterion according to the Cockroft-Latham [14] has the value of the integral (CL), which is expressed in a modified form in the relation:

$$C = \int_0^{\varepsilon} \frac{\sigma_1}{\sigma_i} d\varepsilon \quad (1)$$

where: σ_1 – the largest main stress,

σ_i – equivalent stress,

ε – strain.

To determine the moment of crack it is necessary to know the limiting value of the integral defined by the formula:

$$C_{gr} = \int_0^{\varepsilon*} \frac{\sigma_1}{\sigma_i} d\varepsilon \quad (2)$$

where: $\varepsilon*$ – limiting strain of cracking,

the rest of the markings as in equation (1).

The limiting value of the integral depends on temperature and the speed of the deformation. As demonstrated in research presented in the specialist literature the integral also depends on of the stress state, which poses a fundamental problem in identifying a universal limiting value, which can be used for all processes [15]. However, in order to analyze the process for splitting cracking it is assumed that the limiting value of the integral defining moment of crack initiation for the analyzed material is C_{gr} = 0.2174 [16]. Figure 5 shows the value of the integral C-L during the process in external point of billet pipe, for sample process of splitting of billet pipe. As shown in the graphs the integral reach the limiting value in time 8,8 s.

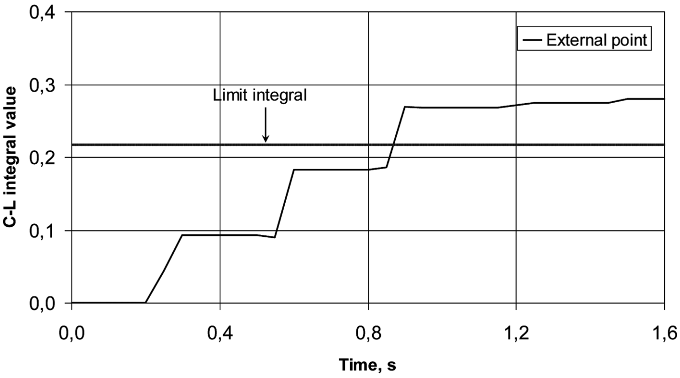

Fig. 5. Value of equivalent stresses calculated according to Cockrofta-Lathama hypothesis in function of time at: D =20 mm, d =14 mm, α =45°, θ =3°

During analysis of brittle was stated that brittle fracture will take place if the following condition is fulfilled:

$$\sigma_v = \sigma_1 - \upsilon \cdot (\sigma_2 + \sigma_3) = Rm \quad (3)$$

where: σ_1, σ_2, σ_3 – value of main stresses,

υ – Poisson's ratio (for alloy 2618A assumed υ =0,342),

Rm – tensile strength (for alloy 2618A assumed Rm= 370 MPa).

On the basis of the calculated values of main stresses for points lying on the inner and outer wall of the billet in the separation point the designated value of the stress σ v during the process was calculated. The results were presented in Fig. 6. On the basis of calculations results it was stated that both at the groove forming stage and at the bending stage stresses change cyclically. Maximal main stresses change their values fluently every half rotation of the billet. From data present in Fig. 6 result that in time 0,4 s corresponding with 0,1 rotation of the billet at bending stage, value of stresses σ_v reaches the value of tensile strength. According to the assumed hypothesis, it is the moment when the beginning of cracking takes place. The equivalent stresses σ_v reach the largest values in the external layer of the billet, hence, initial cracking should take place there.

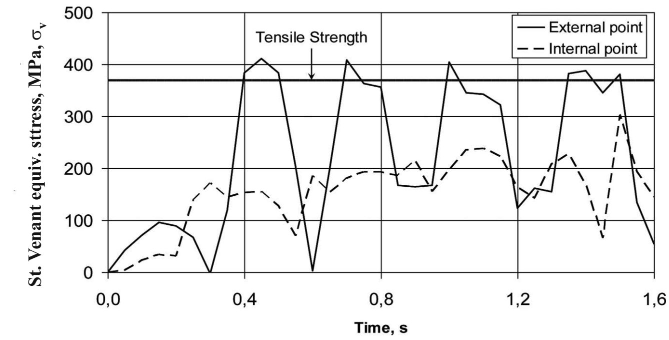

Fig. 6. Value of equivalent stresses calculated according to de Saint-Venant hypothesis in function of time at: D =20 mm, d =14 mm, α =45°, θ =3°

On the basis of results in the conducted analysis of state of stresses it was stated that in the splitting process brittle cracking takes place. The results of stress analysis revealed that in the process of separation occurs before brittle fracture.

It was, however, noticed that the larger is the value of bending angle θ and reduction ratio Δr, the value of stresses σ_v at the bending stage is larger as well. Hence, these are parameters acting on splitting cracking phenomenon. It was observed, that the change of the value of the forming angle α does not contribute to the difference of reduced stress, so this parameter has no important influence on course of splitting cracking.

4. Experimental research

On the basis of the conducted theoretical research, a set of tools was designed to conduct experimental research. They are dividend and consist of mounting knife and bending pad (Fig. 7).

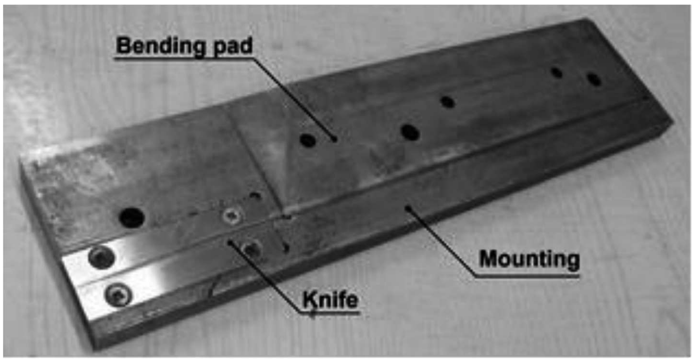

Fig. 7. Tools used in research

In research, knives of angles α equal 45°, 60° and height Δr =2 mm were applied. Bending pads had bending angles θ

equal 1°, 2° and 3°. Pipe billets of external diameter Ø20 and internal diameters equal Ø10 mm, Ø12 mm, Ø14 mm, Ø16 mm and Ø18 mm corresponding with wall thickness g from 5 mm, 4 mm, 3 mm, 2 mm, 1 mm respectively were split. Billets were made from pipes squeezed from aluminium alloy 2618A. Experimental research were done using a flat-wedge rolling mill LUW-2, equipped with the measurement for the tangent component of forming force and tool movement in the function of time.

Examples of forgings which underwent splitting are presented in Fig. 8. It can be observed that from outside a glittering ring formed in the process of groove rolling can be seen. From the billet inside a ring-shaped area is visible, which appeared in the result of cracking. Its features such as rough, mat appearance and relatively large irregularity are characteristic for brittle cracking which confirms the results of theoretical analysis.

Fig. 8. Pipe forgings after splitting at forming angle α =45° and bending angle θ =3°

A crucial parameter of the process constitutes forming forces, knowledge of which is necessary for the choice of aggregate for the process realization. Forming force can be divided into three components: tangent F_x, radial F_z (forming) and axial F_y (directions of axis x, y, z according to Fig. 3). During the research the tangent component Fx of forming force was analyzed. Its course in function of time in comparison with the components of force set theoretically for a sample is shown in Fig. 9. On the basis of calculations and their results it was stated that at the beginning of the process (groove forming, t<0,37 s), tangent component F_x (experimental and theoretical) and radial component F_z gradually increase their values until the wedge cuts into its whole height. Next, forces F_x gradually lower, which results from removing of cross section ovalization present in the area of the formed groove. At this stage of the process axial component F_y is almost equal zero, which results from symmetrical construction of the wedge forming the groove. During the second stage of the process (bending stage, t>0,39 s), all three components of forming force are present. The largest values assumes the radial force F_z and it is about 9 times bigger than tangent force F_x and near 7,5 times bigger than axial force F_y. Tangent force F_x is very low in this stage of the process. It is worth pointing out that course and value of measured tangent force show large convergence with results obtained in theoretical analysis, which means that theoretical model is of good quality.

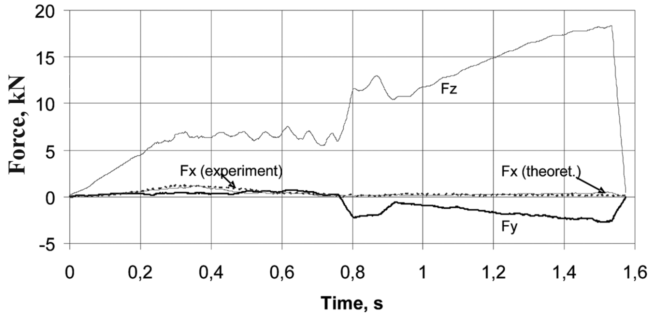

Fig. 9. Course of tangent component of forming force in function of tool movement for the process realized at: D=20 mm, d=14 mm, α =45°, θ =3°

5. Conclusion

Theoretical and experimental research works confirmed the possibility of splitting without waste process application in relation to pipe billets from aluminium 2618A in the area of wall thickness.

The splitting surface consists of two areas: a glittering and smooth formed in the process of groove rolling and rough, and mat formed as the result of cracking. The first area is inclined and the angle can be adjusted with forming tools α. This is important when you need to chamfer the edges of the billet (eg, prior to welding). In such cases the presented method to split the pipe to avoid additional chamfering of edges, performed usually by rolling.

Results of theoretical analysis including criteria of cracking show that in the process of splitting without waste of pipe billets from the analyzed alloy, brittle cracking takes place. It is also confirmed by the analysis of splitting surface which is rough and mat.

The results of research and experimental research confirmed that the largest values reaches the radial component of the forming force. In case of too low rigidness of machine body its deformation can influence the reduction of the bending angle θ and reduction ratio Δr, consequently, reduce the intensity or prevent the process of splitting.

The results justify the necessity for further research on the use of the new method to split billets pipes without waste from other materials.

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