flanging, hollow parts, AlMgSi alloy, FEM

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COMPUTER-AIDED ANALYSIS OF A NEW PROCESS FOR FLANGING HOLLOW PARTS

Abstract

The paper presents a new process for flanging hollow parts. This process is performed using a specially designed set of tools with movable sleeves. The principle of operation of the tool set is described and examples of the numerical analysis results are given. The FEM simulation was performed on the assumption that the hot-formed hollow workpiece (tube) is made of AlMgSi aluminum alloy. The obtained FEM results show changes in the workpiece shape during flanging, variations in the forming force and the damage function distribution computed according to the C-L failure criterion. The theoretical results of the new flanging method provided basis for experimental tests.

1. INTRODUCTION

Hollow parts find more and more applications in numerous sectors of industry. Given the constant pursuit of machinery producers to reduce weight of machines, new technologies for producing individual parts need to be developed; also, this requires that materials with the lowest possible density and, at the same time, high immediate and fatigue strength be used. For this reason, magnesium, aluminum and titanium alloys are more and more often industrially applied due to their low density and relatively high strength. Nonetheless, the cost of these alloys is relatively high, which can be an obstacle to series production. Hence, if these materials are to be used, technologies that enable increased material yield must be implemented.

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Currently used methods for producing flanged hollow parts mainly consist in connecting the hollow part with the flange by welding, pressure welding or soldering. These methods cannot however be employed to produce solid parts, for example ones that are used in the aviation industry. To produce such parts, machining is applied, where solid or hollow bars are used as semi-finished products. Other metal forming methods can be applied, too, for instance flanging of tube ends by rigid tools performing a translational [1] or translational-rotary motion [2]. There are also studies on the flanging of an end of tube (sleeve) by orbital forging [3] cold upsetting-extruding [4] and cross-wedge rolling [5]. These methods, however, reveal some limitations, such as a disadvantageous state of stress in the deformation zone, low effective strain as well as quickly occurring cracks. In addition, the thickness of walls of the flanges produced thereby is lower than the thickness of the billet wall.

The present paper describes a new flanging method [6] which ensures producing a part that is free from the defects that occur in the flanging of tube ends.

2. NEW PROCESS FOR FLANGING

2.1. Description of the process

The forming process for flanged hollow parts is characterized by a number of limitations, which means that there are few methods that enable producing defect-free parts. The higher the flange-to-core-diameter ratio D/d (Fig. 1), the more difficult the process for producing the part by metal forming methods.

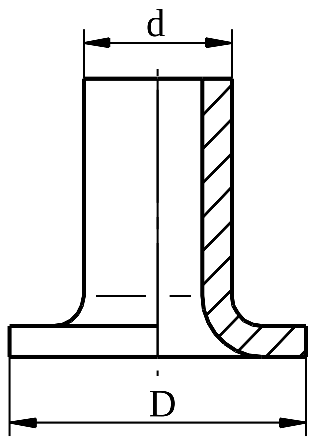

Fig. 1. Typical hollow part with a flange [source: own study]

The fundamental limitation of the flanging process is radial cracking caused by circumferential tensile stresses. The stresses increase with an increase in the flange diameter, which means that the process can be carried out only until the occurrence of first cracks, as cracking prevents obtaining the maximum flange diameter from the billet. The effect of the circumferential tension of the flange is that the further it is from the axis of the hollow billet, the higher the decrease in the flange thickness.

One advantage of the new proposed method for flanging hollow parts [6] is that it overcomes the above mentioned technological limitations, which means that parts produced with this method have better quality compared to those produced by other methods. Another benefit of the process is that it enables producing a flange with constant thickness; the thickness can be equal to or lower/higher than the thickness of wall in the non-deformed fragment of this part.

The flanging process consists in forming a flange in three stages according to the schematic shown in Fig. 2. The tool consists of a mandrel, punch, two movable sleeves, one internal sleeve and one external sleeve. A tube section is put on the mandrel and inside the internal sleeve. The internal sleeve prevents the billet from buckling, while the mandrel prevents radial flow of the material toward the inside. Initially, the two movable sleeves are located on the frontal surface of the mandrel; the spacing between the internal sleeve and the frontal surface of the mandrel is equal to the flange thickness (Fig. 2a). Flanging takes place due to the impact of the punch on the billet. The punch moves until the free space between the internal sleeve, first movable sleeve, punch and mandrel is completely filled up with the material (Fig. 2b). When the punch is stopped, the first movable sleeve is lifted by a value equal to the thickness of the flange being formed. Due to the lifting of the sleeve the process can be continued because there is some new free space created; this time, the space is created between the internal sleeve, both movable sleeves, punch and mandrel (Fig. 2c). As previously, flanging is continued until the space between the tools is completely filled up with the material. With the punch stopped, the second movable sleeve is lifted, and flanging can be carried out again (Fig. 2d).

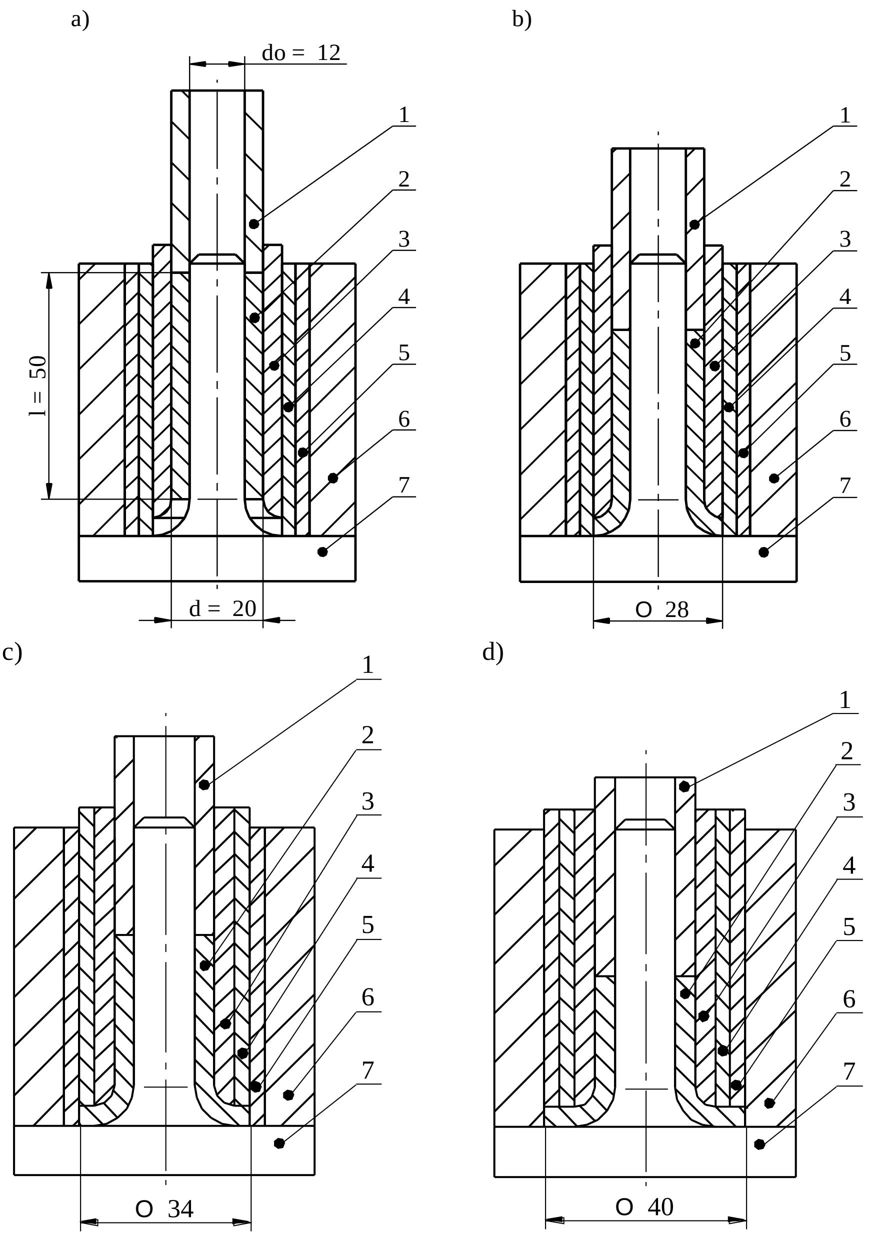

Fig. 2. Design of the flanging process, where: 1 – punch, 2 – workpiece, 3 – internal sleeve, 4 – first movable sleeve, 5 – second movable sleeve, 6 – external sleeve, 7 – mandrel, a) initial stage of flanging, b) first stage of flanging, c) second stage of flanging, d) third stage of flanging [source: own study]

2.2. Numerical model of the process

The numerical analysis of the flanging process was performed by the finite element method using DEFORM-3D. In the simulations, the mandrel, punch, movable sleeves, internal sleeve and external sleeve (Fig. 2) are rigid bodies, while the billet is a deformable body divided into four-node tetragonal elements and described by a rigid-plastic model. It was decided that the billet would be made of AlMgSi aluminum alloy, the material properties of the alloy were taken from the library database of the program. The initial dimensions of the billet (Fig. 2) were: (d x d0 x l) : ø20 x ø12 x 50 mm. Following the forming process, a flanged tube with the external diameter D (Fig. 1) equal to 40 mm is produced. The initial temperature of the tools was set to 300 °C, while the billet temperature was set to 450 °C. The punch velocity applied in the calculations was maintained constant at 100 mm/s. The tool-billet contact conditions were described by a constant friction model, with the friction factor m set to 0.3 and the tool-material heat exchange coefficient set to 14 kW/m^2K.

The model of material damage applied in the calculations corresponded to the modified Cockcroft-Latham criterion [7]:

$$\int_0^{\varphi^*} \frac{\sigma_1}{\sigma_m} d\varphi = C \tag{1}$$

where: φ^* – the effective strain,
σ_1 – the largest principal stress,
σ_m – the mean stress,
C – the critical damage parameter.

2.3. Numerical analysis results

Figs. 3a, 4a and 5a show changes in the workpiece shape in three stages of flanging and the damage function distribution respectively at the end of the first, second and third stage of the process performed with the movable sleeves. In contrast, Figs. 3b, 4b and 5b present analogous numerical results for the flanging process performed using the internal sleeve only.

The initial phase of individual stages of flanging are similar to the flanging process performed without the use of the movable sleeves. The material is deformed until it contacts a check surface (the first or second movable sleeve, or the external sleeve). The contact between the material and the check surface accounts for the use of the movable sleeves and external sleeve. The initial phase is relatively short compared to conventional flanging methods [8-10].

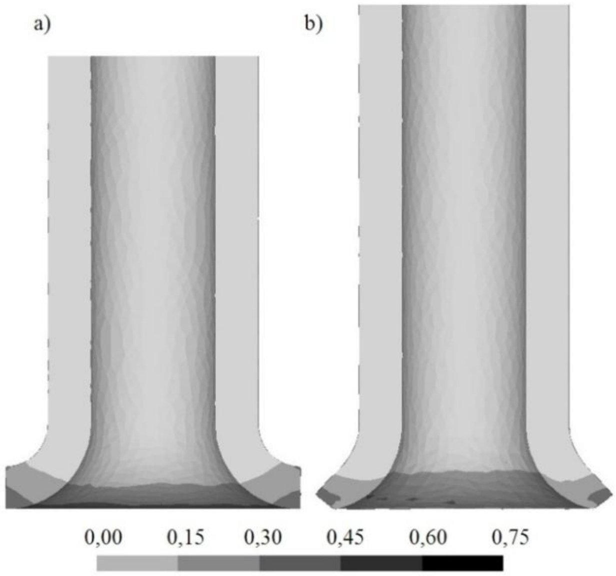

Fig. 3. Changes in the workpiece shape and the damage function distribution (calculated according to the Cockcroft-Latham criterion) in the first stage of the flanging process: a) flanging with a movable sleeve, b) flanging with an internal sleeve [source: own study]

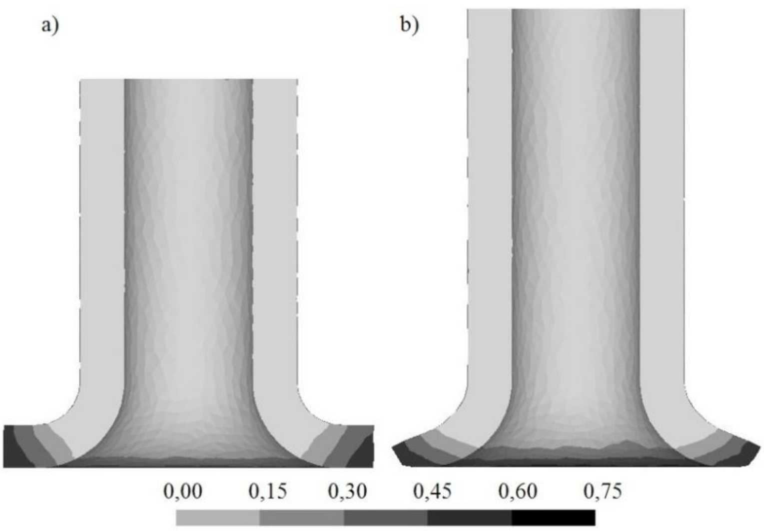

Fig. 4. Changes in the workpiece shape and the damage function distribution (calculated according to the Cockcroft-Latham criterion) in the second stage of the flanging process: a) flanging with a movable sleeve, b) flanging with an internal sleeve [source: own study]

The calculation results demonstrate that it is vital that the first movable sleeve have the smallest possible internal diameter, which allows reducing the time of unconstrained material flow. Nevertheless, given the assumption saying that the thickness of the flange is equal to the thickness of the tube wall, the internal sleeve has a rounding with a radius equal to the tube wall thickness. Hence, the resultant value of the internal diameter of the first movable sleeve is 28 mm, which is equal to the diameter of the flange produced in the first stage.

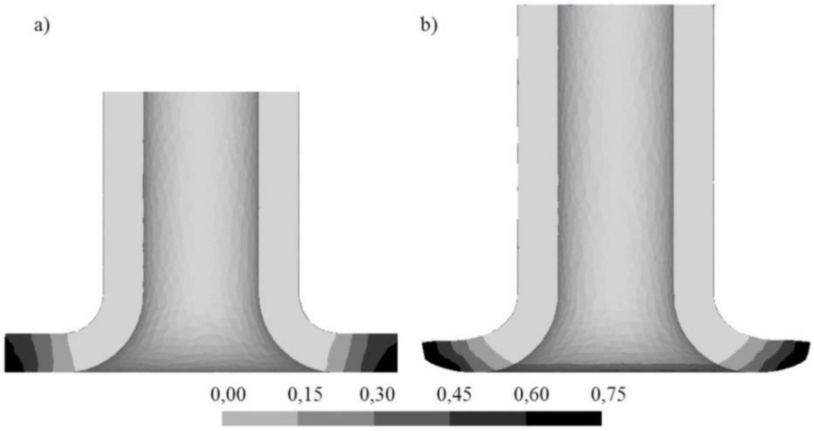

Fig. 5. Changes in the workpiece shape and the damage function distribution (calculated according to the Cockcroft-Latham criterion) in the third stage of the flanging process: a) flanging with a movable sleeve, b) flanging with an internal sleeve [source: own study]

After the contact with the first movable sleeve, the flange diameter does not increase any further. What increases is the thickness of the flange; simultaneously, compressive stresses are generated and they should prevent radial cracking. It is also worth observing that lapping does not occur when the flange thickness is being increased. This stage is characterized by the fact that the internal edge of the billet (one that is changed into the lower external edge of the flange) remains in constant contact with the surface of the mandrel until it contacts the first movable sleeve. When the thickness of the flange is equal to the that of the billet wall (Fig. 3a), the punch is stopped and the first movable sleeve is lifted by a value equal to the flange thickness; after that, the punch is set into motion again. And the second stage of the flanging process begins (Fig. 4b). In this stage, the flange diameter increases from 28 mm to 34 mm. Like in the first stage, the increase in the flange diameter immediately results in a decrease in the flange thickness, which can be observed until the flange contacts the second movable sleeve. The decrease in thickness is lower than was the case in the first stage: the increase in the flange diameter in the second stage is lower by 25% compared to the decrease which took place in the first stage.

Summing it, individual stages of the process are characterized by a number of differences. Unlike in the first stage, in the second stage of the process the lower external edge of the flange does not contact the mandrel surface, while the upper external edge of the flange does not contact the first movable sleeve. In the third stage, the lower external sleeve of the flange does not contact the mandrel surface, either; yet the upper external edge of the flange contacts the second movable sleeve. Local changes in the direction of material flow can therefore be observed in individual stages of the flanging process.

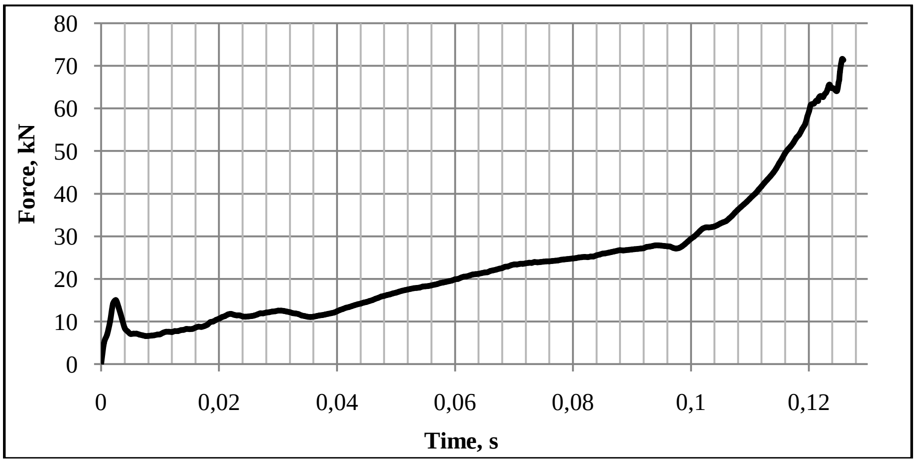

Fig. 6. Forming force versus time in the first stage of the flanging process [source: own study]

The differences also pertain to variations in the forming force (Figs. 6-8). At the beginning of the first stage, the force exerted by the punch on the billet increases at a slow rate, almost in a linear fashion, until the billet contacts the first movable sleeve. From this moment on, the increase in the force versus time is higher, reaching the maximum value of about 70 kN. In the second and third stages of flanging, the forming force is initially almost constant, equal to 35 kN and 42 kN, respectively. As soon as the billet material contacts the second movable sleeve or external sleeve, the increase in force versus time is almost constant, reaching the maximum value of about 70 kN, both in the second and third stage.

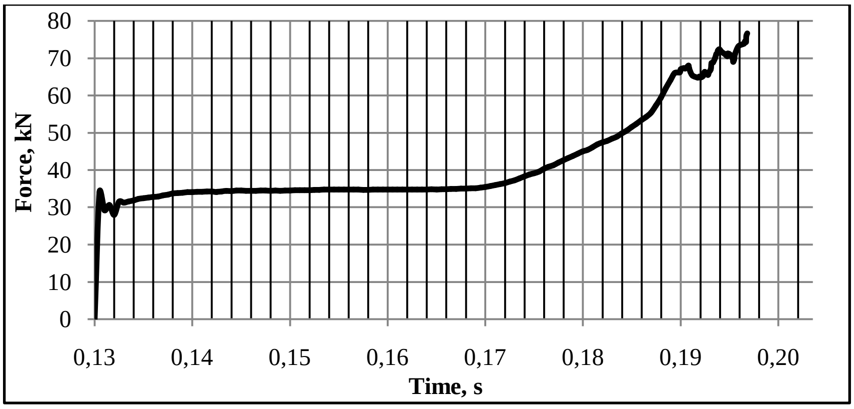

Fig. 7. Forming force versus time in the second stage of the flanging process [source: own study]

The maximum values of the forces in particular stages of the process are similar. Differences can only be observed in the initial phases of particular stages, i.e. only until the flank of the flange remains unconstrained by the movable sleeves or external sleeve.

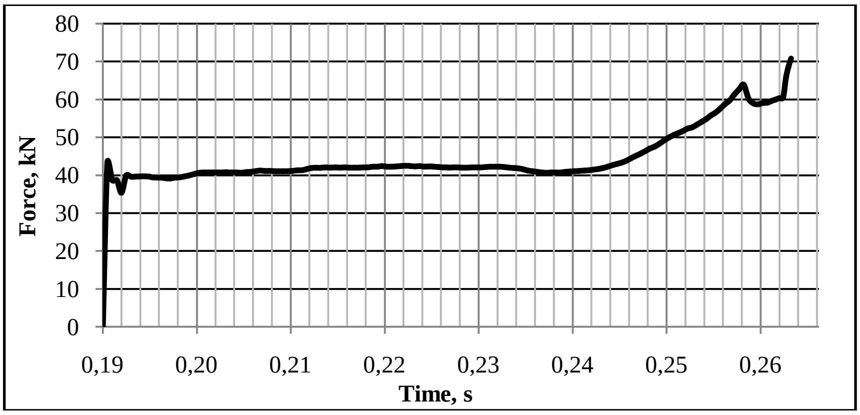

Fig. 8. Forming force versus time in the third stage of the flanging process [source: own study]

The stabilized value of the force in the initial phase of the second stage is 35 kN, while in the initial phase of the second stage – it is 42 kN. The increase in the force is caused by the increase in the flange diameter. Nonetheless, the variations in the forces are relatively small because the increase in the flange diameter leads to a decrease in the length of the flanged sleeve; this, in turn, results in decreased friction forces between the tubular part of the sleeve and the mandrel and the internal sleeve in the total forming force.

Comparing flanging with the movable sleeves to flanging based on the use of the internal sleeve only, the following differences can be observed (Figs. 3-5): the application of the movable sleeves allows producing a flange with a thickness equal to the thickness of wall of the tube on which the flange is made. The flange thickness is constant, irrespective of the distance from the billet axis and flange diameter. flanging leads to a decrease in the flange thickness along with an increase in its diameter. The damage function distribution presented in Figs. 3-5 is similar to both flanging performed without the use of the sleeves and flanging performed with the movable sleeves. The longer the distance from the axis of the billet, the higher the value of the C-L function. Small differences can only be observed in particular zones. For example, the damage function distribution given in Fig. 5 shows that the maximum value of the examined damage function is 0.75, which pertains to the part of the flange with the diameter exceeding 28.8 mm and 24.1 mm for flanging performed with the movable sleeves and without these sleeves, respectively. As a result, the application of the movable sleeves prevent radial cracking in the flange.

3. CONCLUSIONS

The paper presented a new process for flanging hollow parts. The proposed method consists in forming a flange in three stages using two movable sleeves. The FEM simulations were based on the assumption that the movable sleeves have a wall density of 3 mm. The proposed value can be higher or lower; also, there can be more than just two movable sleeves. It is expected that increasing the number of movable sleeves and decreasing their wall thickness will have a positive effect on the quality of the flange being formed. It is demonstrated that the application of the movable sleeves enables forming a flange with constant thickness irrespective of its diameter. In addition, the application of the movable sleeves helps prevent radial cracks on the flange.

By using specialized computer software (DEFORM-3D and Solid Edge), it is possible to further analyze the process. The use of computer techniques accelerate research and reduce their costs.

Further research on the process will focus on determining the effect of the wall thickness of particular movable sleeves and the number of movable sleeves on the process feasibility and product quality.

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