

TWO DIMENSIONAL U-BENDING MODEL APPLIED TO A ALUMINIUM BLANK

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Abstract. A U-bending process is modeled for the analysis of a blank made of aluminum. Geometry of punch, holder and die is first set. Material properties of aluminum blank required in the constitutive equation for the elasto-plastic behavior is constructed next. Initial conditions involving holder pressure, kinematics of equipment pieces and tangential friction are prescribed in a sequence of steps to prepare for punch action. Principle of virtual work, in incremental form, is used to determine displacements and configurations of the blank. From this information, stresses, strains and contact conditions are computed to show the evolution of geometry, having in mind failure modes associated with damage of the material.

Keywords: U-bending, aluminium, elasto-plastic behavior, stress and strain evolution, configurations

1. INTRODUCTION

The problem of bending a strip of metal in a bending machine, of fixed geometry components – punch, holder and die – with a U design is analyzed here. In the analysis finite element method, in an incremental form, is used to determine the displacement field, stress and strain components. Contact normal and tangential components are also computed with inclusion of frictional effects. At every configuration from unloaded initial to final conformed position these resulting fields are computed as well as punching and die efforts.

2. METHODOLOGY

The part to be conformed, the blank element, is a strip of metal with length l , thickness h and unitary width w . Acting elements in the process are the punch, holder and die. They are modeled as rigid parts. Their geometry has linear and curve portions integrated by curvature fittings. In the initial configuration these elements are set apart with space for the positioning the blank and clearance for motion of acting elements. Forming operations comprise some steps.

In order to simulate the process, these elements are initially drawn one by one in computer, have material and sectional properties assigned, before they can be disposed in a set called assemblage. Initial positions in the assemblage consider initial contact conditions. In the modelling, holder and die initially touch the blank. Holder fixing pressure is applied next to the blank, squeezing it, step 1. Forming of the blank occurs when the punch makes contact with the inner portion of the blank and moves it downwards, step 2. Boundary conditions consider symmetry of displacements in the center of the blank. Kinematics settings fix all parts but the vertical displacement of the holder in step 1 and the specified punch displacement in step 2. Contact between parts and blank requires master-slave pairs to be chosen, with normal and tangential components existing. Frictional contact between blank and holder and die are chosen. Non-frictional conditions are considered in the punch-blank interface.

Problem is solved using the principle of virtual work in rate form. As contact forces are applied as a result of interaction of rigid elements with the blank, reaction forces are computed from equilibrium efforts in the reference point in the die. From equilibrium, reaction efforts, stress and deformation fields of the blank are obtained in the first step. In the second step, from initial up to final configuration when punch reaches its final displacement, applied force is computed from applied displacement. Process requires several iterations, of different size in numbers that round one thousand. Quasi-static conditions are considered all over. Open die is used.

2.1 U-bending Elements and Characteristics

Drawings of U-equipment, require geometry of punch, holder and die to be specified. Due to symmetry only half of the pieces need to be modeled. Punch used in the model has length $L_p = 120$ mm with height $H_p = 60$ mm with fillet radius $R_p = 5$ mm Fig. 1. It is constructed with steel. Side holders, left and right, measure $L_h = 60$ mm by $H_h = 60$ mm with the same fillet. Each side die, left and right, has dimensions identical to the corresponding side holder. Blanks have semi-length $l = 100$ mm by $h = 1$ mm thickness. Holder-punch and die-punch clearance is set to 1 mm. Unitary dimensions apply perpendicularly to plane. Friction coefficient is set as 0.10 (Kalpakjian, 2009)

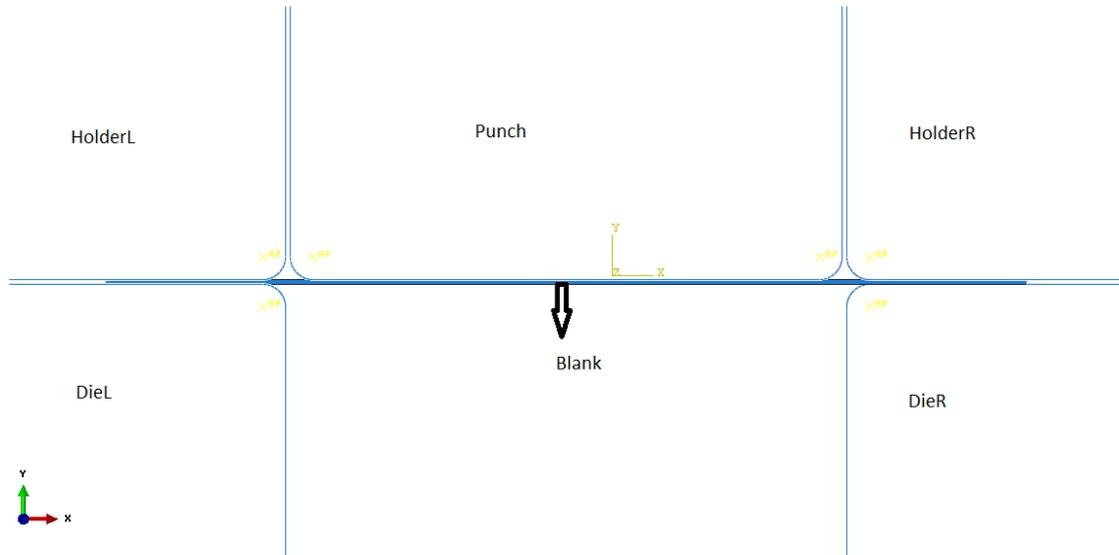


Figure 1. Contour plotting of U-bending set of elements used in the model: only blank is deformable

2.2 Material Stress-Strain Curve

Blank material is aluminum whose properties come from 1D stress-strain data curves, under quasi static conditions, with no thermal coupling included as show in Fig. 2. From the curve, stress-strain data for the elasto-plastic region is extracted assuming constant elastic modulus $E = 69.56e+09$ Pa. The resulting plastic-stress $S(\bar{\epsilon}_p)$ versus plastic equivalent strain $\bar{\epsilon}_p$ curve, for different points along the diagram, as required in the model, is constructed (JOVE, 2019). Values range from $S_{yt} = 223.e+06$ MPa at yield up to ultimate strength $S_{ut} = 372.75e+06$ MPa.

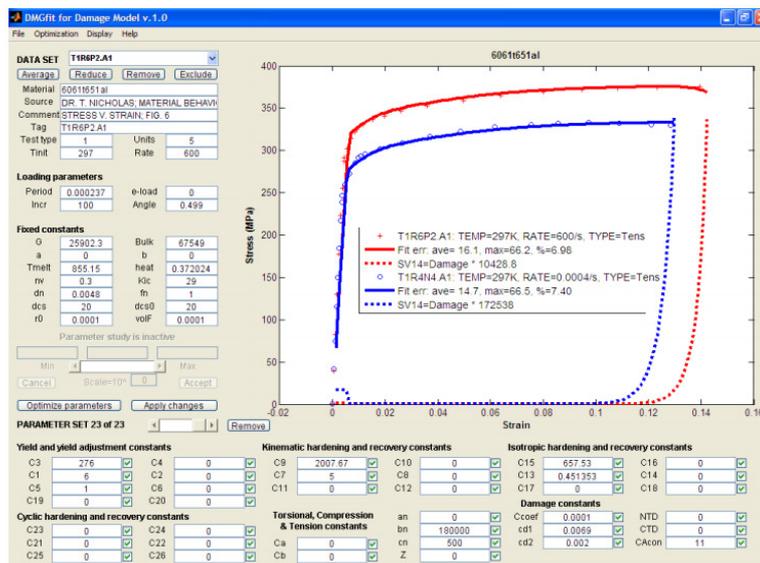


Figure 2. Complete data for stress-strain curve of aluminum 6061T6

2.3 Principle of Virtual Work

In any configuration the blank is under the action of contact efforts, in its superior S_c^u and lower surface S_c^l . Contact stresses comprise normal $-p$ and tangential τ_t components, associated with displacements components u_n and u_t . Virtual work in these surfaces include the work of tangential stresses over relative tangential displacements as well as normal stresses over the relative normal displacements.

Considered some specific configuration, contact virtual work contribution in superior and inferior surfaces of the blank are in general different: δW_c^s and δW_c^i . Between configurations these quantities are incremented due to changes in contact geometry. Friction supposes no slip in penalty model used. A part the virtual work of contact, the deformation work over the blank material δW_d is present. The process is quasi-static. Equilibrium requires then, this sum null. Therefore, between different equilibrium configurations, the increment of the sum has to be, (Bathe, K.J., 1996)

$$\partial(\delta W_d + \delta W_c) = 0 \quad (1)$$

where in the incrementation process due care has to be placed in changes of geometry with updating including rotation effects and stress measures. Expressions below refer to the work terms for unitary dimensions in direction perpendicular to the page:

$$\delta W_d = \int_{S_i} \boldsymbol{\sigma} : \boldsymbol{\delta \epsilon} dA \quad (2)$$

$$\delta W_c = \int_{L_t} \boldsymbol{\tau}_t \cdot \boldsymbol{\delta u}_t dS + \int_{L_n} \boldsymbol{\tau}_n \cdot \boldsymbol{\delta u}_n dS \quad (3)$$

Solution of U-bending problem is developed after general boundary conditions are set. Position of the holder and die, as well as punch, are initially given. Next lateral holders apply a holding force $F_h = 1.02 + 05 \text{ N}$ to the blank with the die fixed touching the blank. Downwards punch motion is ensued in the second step, $d_p = 20 \text{ mm}$, so as to deform the blank. Boundary conditions for the description of the motion of the punch prescription include symmetry conditions for the blank, restrictions of motion of the punch to the vertical direction during the process. Contact with the different surfaces is set by means of interactions using penalty method with no interference allowed. Plane strain conditions are supposed. Punch force at the end of application is $F_p = 17.029e + 3 \text{ N}$.

3. RESULTS

For any configuration in the process, stress and strain tensor inside the blank are computed. From these Mises stresses are determined at any of the increments, for any element of the blank mesh of 4×400 elements type CPE4R of finite element program (Abaqus, 2013) used in the endeavor. At the end of punch motion, geometry and stress distribution in the blank is as shown, Fig. 3.

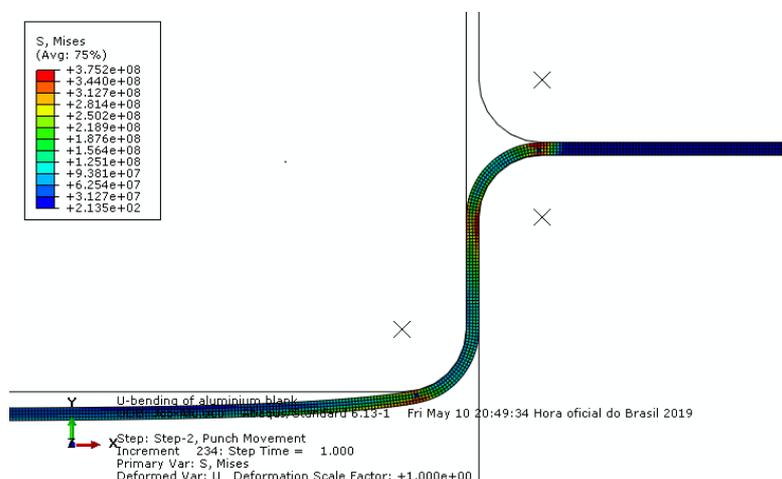


Figure 3. Mises stress distribution along the blank at final configuration

In a few points, it can be seen that stresses reach ultimate value and that displacement field of the punch does not coincide with that of the blank in their common interface. This stress field in the blank evolved from the one imposed by holder force shown in Fig. 4.

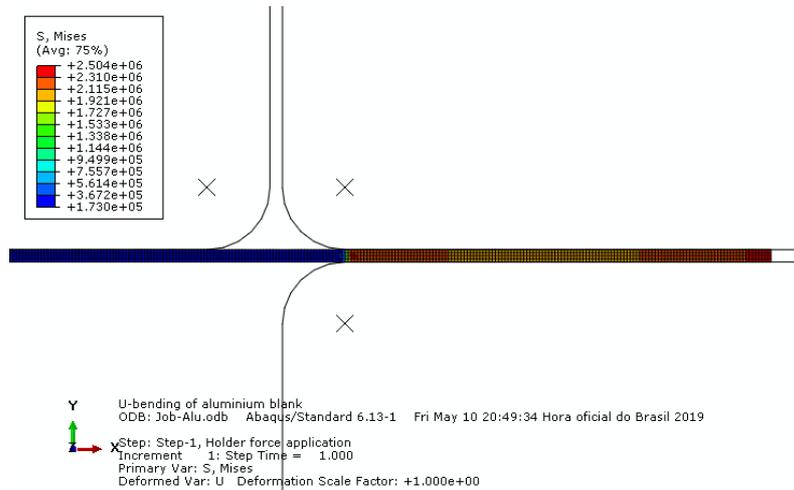


Figure 4. Mises stress field in the blank after holder force application

Maximum values of plastic strains in the blank at the end of the punch movement, important in determining spring back effect is included below, Fig. 5. Curvatures introduced by the fillets are clear factors in setting the intense bending in regions of processing.

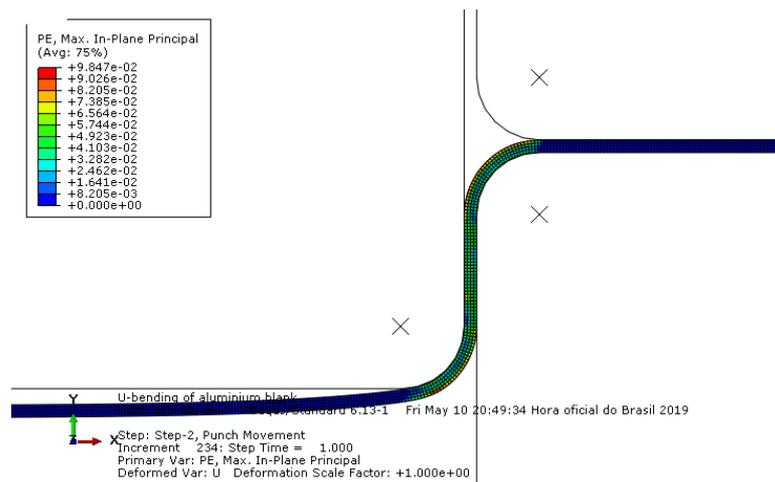


Figure 5 Maximum plastic strain distribution at the blank at final position of punch

Shear stresses accumulated along the processing of the blank appear in the outer surfaces of the blank with values in the yellow range. At the contact points they are circa $3.e+06$ MPa. Contact pressures are null everywhere, but at the curvature change points,

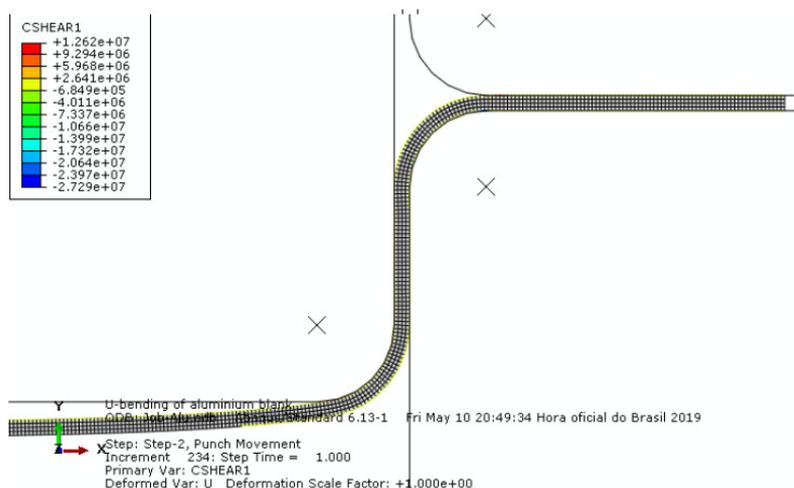


Figure 6. Contact shear stress accumulated in the processing of the blank

Reaction forces in the die as a result of the action of the punch over the blank are also determined. They are computed from the integration of the stresses in the interface between die and blank. They are higher than the applied force to the punch during processing. Local failure occurs at some elements, mostly at those located at the outer surfaces of the blank, at regions of higher curvature change, as shown in Fig.7 for the settings used in the problem.

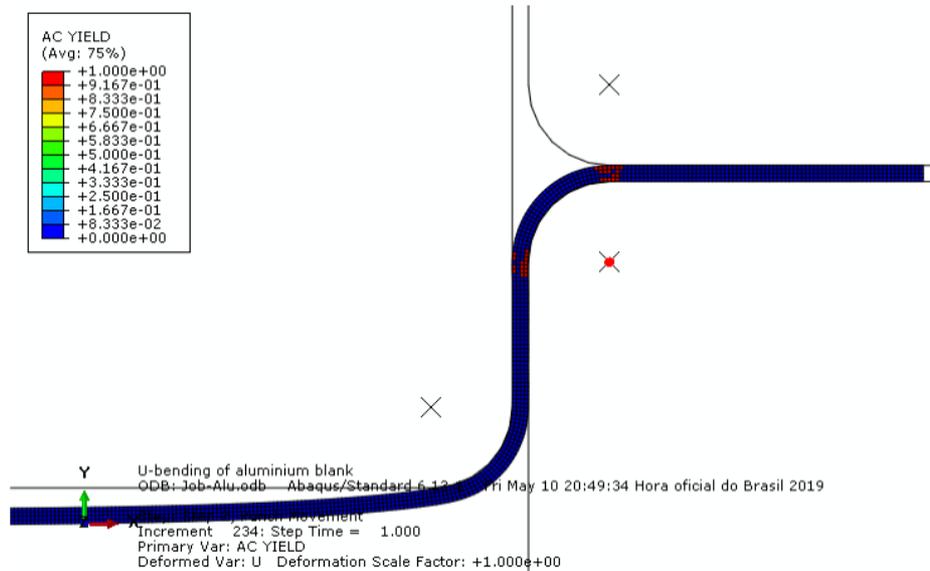


Figure 8. Failure map over the blank at final configuration.

4. CONCLUSIONS

Quasi-static conditions were considered in the analysis presented. No couplings involving thermal effects associated with friction and lubrication were considered, as it is supposed the process is developed at low temperatures. The obtained results show close resemblance to analytical predictions and experimental work, even though adjustments could avoid the presence of the ultimate stress in the field causing surface failures. Model shows that the reaction force at the die, and consequently the applied force in the punch varies during process, reaching maximum values around half of the punch course. Its final value decreases by some 5% when friction is half. Also decrease of 20% of holder force, decreases punch and die forces by about 30%. From the developed model effects of fillet radius, clearances, rate of loading and spring back may be drawn.

5. REFERENCES

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