10th Brazilian Congress on Manufacturing Engineering
August 05th-07th, 2019, São Carlos, SP, Brazil

V-BENDING MODEL APPLIED TO A ALUMINIUM STRIP

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Abstract. *Sheet metal bending is one of the most common operations in metalworking. However, bending still presents key design factors not fully understood like punch load predictions. This article models the punch-die bending of a sheet metal piece using finite element approach. It provides some insights on the stresses distributions during the operation. It investigates bending forces comparing it to the empirical design formulas. It also discuss some parameters affecting the bending operation on a V-die.*

Keywords: *V-bending, aluminum, elasto-plastic behavior, stress and strain evolution, tool forces*

1. INTRODUCTION

The article analyses the bending of a strip of material with a bending machine, of fixed components – punch, metal strip and V-die. The finite element modeling allows the prediction of displacement fields, plastic deformation imposed to the blank, stress fields, with flexural and shear stress components, contact normal pressure and frictional component at every configuration from unloaded initial to final position. From punch, blank and die geometry plus properties of aluminum, included in the constitutive equation for the elasto-plastic behavior, problem is put. The initial conditions involve contact positions associated with contact pressure and tangential friction. Principle of virtual work, in incremental form is used to model displacements and configurations of the blank. From this information, stresses, strains, in an equivalent Mises form are used to recover the development of the piece from initial up to final form (Farsi et Arezoo, 2017)

2. METHODOLOGY

The opening angle is a key geometrical parameter to define V-die and V-punch geometry. The blank, which is the bent strip of metal, has length l =130 mm, thickness t =1 mm and a depth of 20 mm. In addition, the die tool has geometry appropriated to conform to the punch geometry. Some concerns about clearance between pieces need to be included. The tools (die and punch) are assumed to be discrete rigid in the finite element modeling. The use of discrete rigid is a convenient approach since permits both parts to be mashed.

Initially the drawing of the parts, with specification of material and sectional form, is done. The positioning of the parts happens in the assemblage step. Interaction of parts is included next, with contacting parts and properties set. Contact between punch and blank requires a master-slave pair be chosen, with friction existing and a contact pressure being present. The same for the other pair: blank and die. In a plane strain problem, horizontal and vertical displacement have restrictions set as initial conditions. For the punch, blank and die they are defined having in mind that symmetry is present.

A general, non-linear static analysis procedure is chosen. In it, displacements are applied to the punch. At the punch reference point, the software will represent the summed value of the computed reaction forces. In order to do so, once the assemblage is discretized, the equilibrium equations are written. Material properties of the blank have to be included in order to establish constitutive equations for the elasto-plastic material. The blank material is aluminum alloy 6061T6. The stress-strain curve of the material, the tabled values of the yield-plastic strain curve, allows setting the constitutive equation and failure stresses. The solver uses the principle of virtual work, in rate form, to write the equations of the problem. Newton´s method is used to solve the system of equations from initial position up to the point where the punch has deformed the blank until it matches the final form of the die. Process requires several iterations, of different size in numbers that round one thousand.

2.1 V-bending tools and characteristics

Metal bending stresses and punch forces depend on parameters of different types: (a) geometrical: punch opening angle; die opening angle; punch radius; die radius, misalignment between die and punch, etc.; (b) material: mechanical properties of blank material; thickness of sheet work metal; (c) operational: friction developed during contact of surfaces (Marciniak et all,2002). Figure 1 shows some of the geometrical parts involved in the process and dimensions in millimeters. It lists some of the assumptions of the simplified finite element model. The interaction between die-sheet (bottom surface) and punch-sheet (top surface) is a standard surface-to-surface contact. The contact property defines normal forces and tangential behavior in an isotropic penalty function with 10% of friction. Constraint for the die as well for the punch requires assigning rigid surfaces and reference points. Figures 2 and 3 represent the discrete rigid parts used in the finite element model.

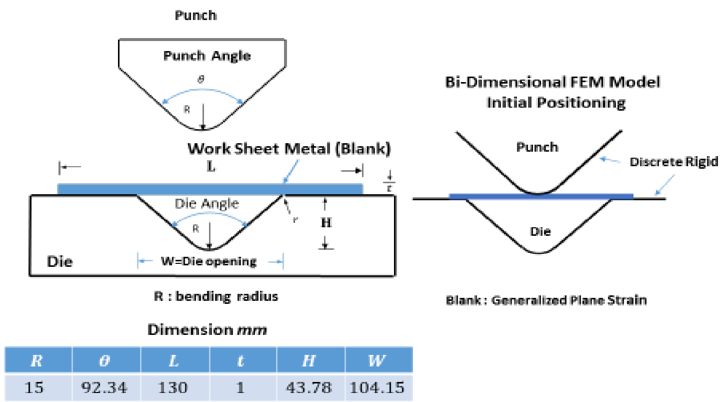

Figure 1. Sketch of the tool set for sheet metal bending

2.2 Design expressions

Standard formulas for punch and die as well blank take into account the bend allowance and empiric bending maximum force expressions. Figure 2 contains the design parameters needed to calculate the bend allowance, length of bending and die force (Vukota, 2004)

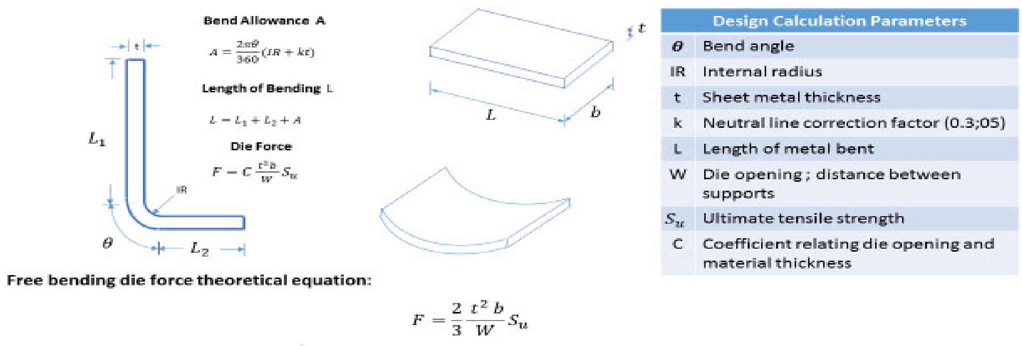

Figure 2. Design formulas for tools.

2.3 Material Stress-Strain Curve

For the aluminum used in the model, properties come from the 1D stress-strain data curve. Figure 3 presents the stress-strain curve for uni-axial extension, under quasi-static conditions, with no thermal coupling. Data extracted from this curve allows the generation of the plastic-stress $S(\bar{\varepsilon}_p)$ versus plastic equivalent strain $\bar{\varepsilon}_p$ curves assuming that the elastic modulus of the material E is constant. Table 1 presents main mechanical properties of the aluminum 6061T6, with general use in aeronautical applications.

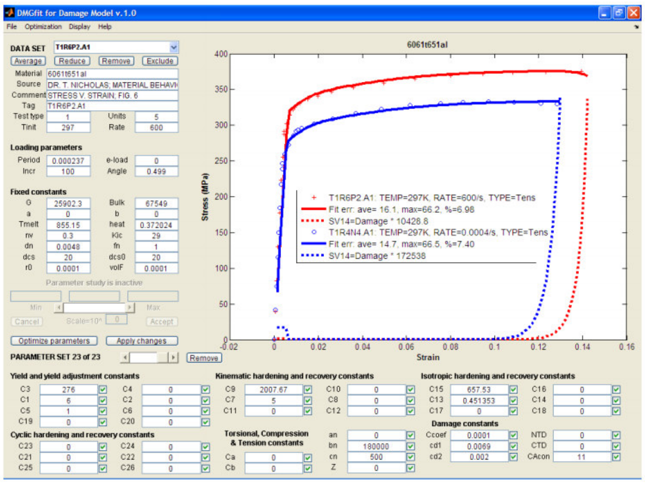

Figure 3. Complete data for stress-strain curve of aluminum 6061T6

Table 1. Mechanical properties of aluminum 6061T6

Elastic Modulus E(MPa)	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Poisson´s Ratio ν	Final Strain
69560	270	338	0.30	0.122

2.4 Principle of Virtual Work

At any configuration the blank, also known as working metal piece, is contacting bending tools: die and punch. The contact develop stresses acting on blank top surface $S_c{}^u$ and bottom surface $S_c{}^l$. Contact stresses comprise normal $-p$ and tangential τ_t components, associated with displacements components u_n normal and u_t tangential. Virtual work in these surfaces include the work of tangential stresses over related tangential displacements as well as normal stresses over the related normal displacements.

Considered some specific configuration, contact virtual work contribution from top and bottom surfaces of the body under contact at that moment are in general different: δW_c^s and δW_c^i. Between configurations, these quantities are incremented due to changes in contact geometry. The modeling assumes friction with no slip condition in the penalty condition. Aside from the virtual work δW_c due to contact between tools and blank material, there is the deformation virtual work over the blank material δW_d. Their expressions are (Bathe, 1982):

$$\delta W_c = \int_{S_t} \boldsymbol{\tau}_t \cdot \delta \mathbf{u}_t dS + \int_{S_t} \boldsymbol{\tau}_n \cdot \delta \mathbf{u}_n dS \tag{1}$$

$$\delta W_d = \int_{V_t} \boldsymbol{\sigma} : \delta \mathbf{e}\, dV \tag{2}$$

Equilibrium requires at any configuration that total virtual work be null:

$$\delta W_d + \delta W_c = 0 \tag{3}$$

Therefore, for different equilibrium configurations in the process of solution, the increment of the sum (Eq. 3) has to be:

$$\partial(\delta W_d + \delta W_c) = 0 \tag{4}$$

So that during the incremental deformation process, there will be changes on the geometry, surfaces, volumes as well as rotations that we have to take into account in the above expressions.

3. RESULTS

Solution of V-bending problem starts by prescribing the initial conditions, where punch contacts the blank. The die holds the blank in position by contacting him. Vertical displacements are prescribed incrementally along the motion of the punch and the required contact forces computed for equilibrium. The blank movement is such as the x-sym happens during the bending operation.

For any configuration in the process, the software computes stresses and strains inside the blank. From these stresses, von Mises stresses are determined at any of the increments, for any element of the mesh used for the blank. For one such a situation, Figure 4 shows the geometry and stress distributions in the blank. At such a position, punch force is about 260. N/mm.

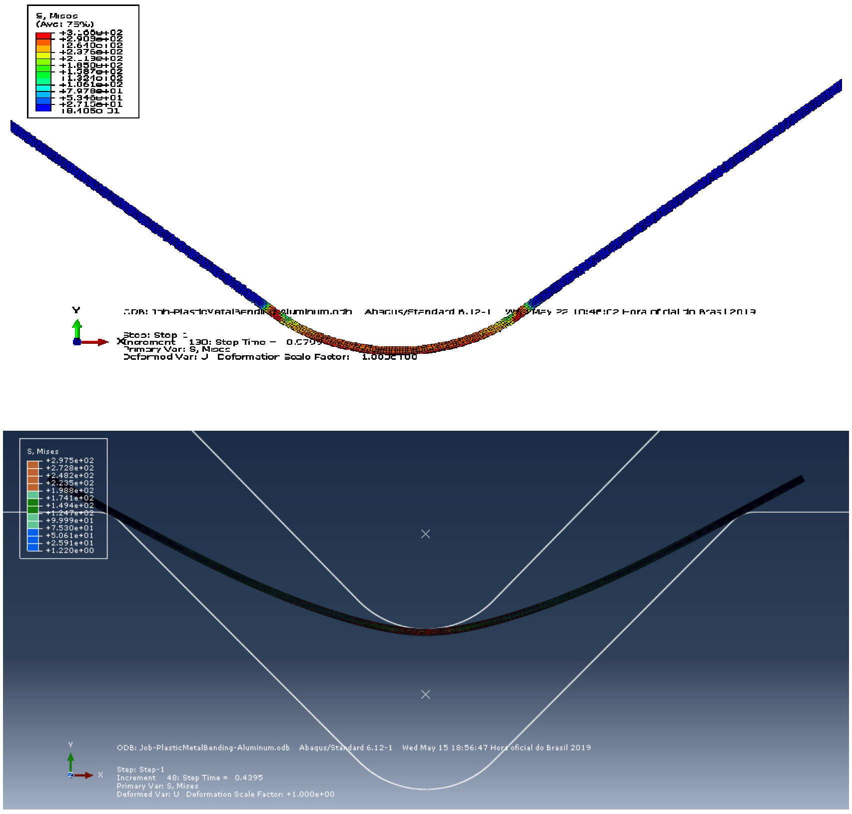

Figure 4. Mises stress distribution along the blank at an intermediate configuration

Figure 5 shows contact pressure distribution at the punch-blank and blank-die interfaces for the same intermediate configuration shown above. Figure 6 presents contact shear, Cshear variable, for the same moment illustrated in Fig. 4. In Figure 7 slip condition at the interface is reviewed, the Cslip variable distribution, so as to verify presence of stick or slip regions along the contacting surfaces.

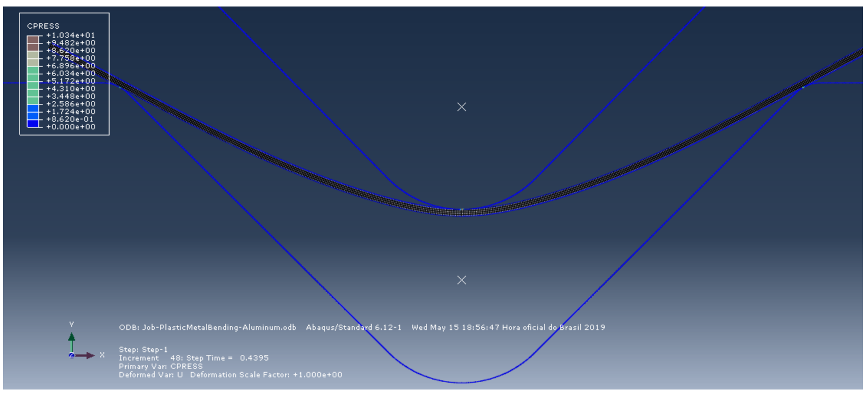

Figure 5 Cpress distribution, partial at the assigned configuration, in the punch and die contact regions of the blank

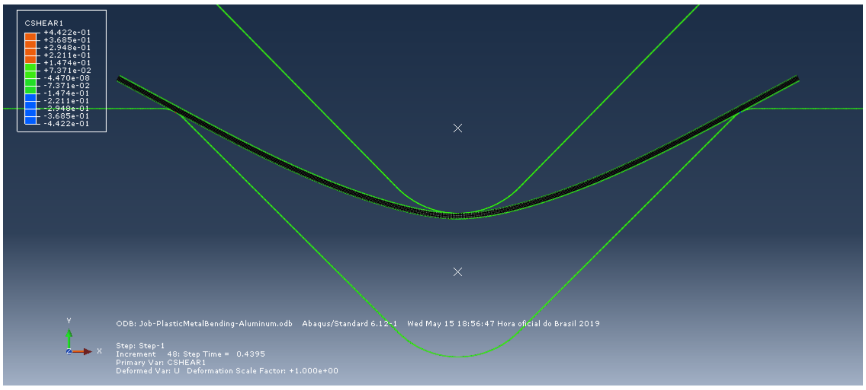

Figure 6. Cshear distribution over the blank at the assigned configuration.

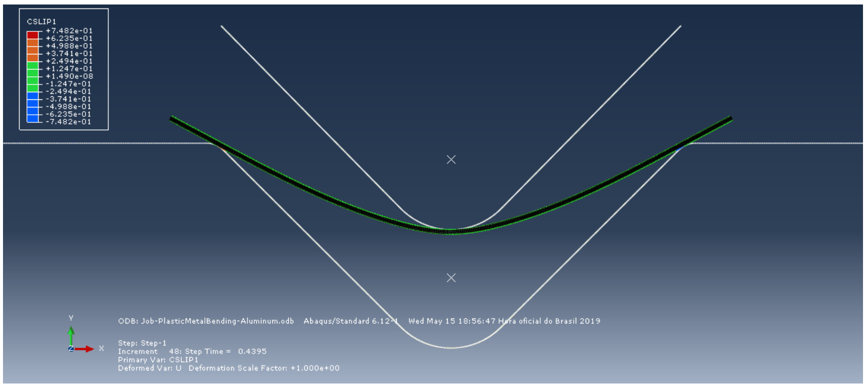

Figure 7. Cslip distribution over the blank in the assigned intermediate configuration

4. CONCLUSIONS

The present analysis considers quasi-static conditions. The deformation process happens at low temperature. No coupling involving thermal effects associated with friction and lubrication need consideration. The obtained results show close resemblance to analytical predictions and experimental work, except at the final stages of deformation. The bent region is in plastic state. However, at the end of the process, plastic stresses appear on most of the blank. Close to ultimate stress value occurs on the surface of the blank in some cases. This occurrence depends on the parameters considered in the analysis and identifies only a surface failure. Friction, in particular, is an important parameter to control in order to avoid this kind of failure. Overall sectional failure wasn´t found in the analysis for the chosen parameter, even though the die opening is considered too large. From the developed model effects of friction, angle of V-punch, rate of loading and spring back may be drawn.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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