Finite Element Analysis of the Parameters Affect the Mechanical Strength of a Point Clinched

Brani Benabderrahmane [1], Benzegaou Ali [2]
[1,2] Mechanics Laboratory: Modeling and Expirementation (L2ME)
Bechar University, Po. Box 417, Algeria.

Abstracts

This work describes a numerical study of the TOX – clinching process and its mechanical strength due to different parameters (geometry of the tools, the friction…). A computer code baptized SEMA "Static Explicit .The FE code is based on an Updated Lagrangian scheme. The used resolution method is based on an explicit static approach. The integration of the elasto-plastic behavior law is realized with an algorithm of Simo and Taylor. The tools are represented by plane facets. A 4-node axisymetric element is used with one-point reduced integration method and hourglass control. The results will be compared to those computed using the static implicit method and those obtained by experimental study.

Keywords: Finite Element Method; Mechanical Strength; Numerical Simulation; Clinching Process; Contact; Large deformation.

1. Introduction

In recent years, mechanical press joining has rapidly developed into a new branch of joining technology. Among the numerous mechanical press joining method, the clinch process is particulary promising. The coming of new products such as sandwich and pre-coated sheets is a major challenge to metallurgists. New assembly method avoiding the destruction of the coating are being developed as complementary or alternatives to point welding. In the present work we consider clinching technique [1]. The latter acts by cold deformation of a number of sheets without any added material [2][3][4]. However, the general rules governing these types of contact are not well defined. The determination of the process parameters (tools geometry, stresses,…) as a function of the assembly characteristics (width of sheets, mechanical characteristics of materials, nature of different coating and the state of the surfaces, conditions of lubrications) is for at present not well described [5][6][7][8].

The present computational work uses a finite element computer code based on static explicit approach [9][10][11]. The clinch forming simulation is compared with experimental results as well as numerical solutions obtained with a static implicit method (computer code ABAQUS).

2. Clinching

Clinching is a mechanical joining process that is mainly intended for sheet metal, in which no additional joining element is used, but the joint is made by forming the plates locally, the importance of mechanical joining techniques involving the principle of cold assembly by metal deformation has clearly appeared [12][13][14][15]. The generic term of clinching designates a set of joining techniques of metal sheets, tubes and sections which act by point formation in one operation without thermal effects. These methods described in [16] allow assembly of pieces by means of insertion by mutual shearing at assembly, with cutting out and / or drive back of matter between a die and a punch. There are different technologies and different types of points (circular, rectangle or bar, cross,…etc). We may however distinguish two main classes of clinched points within points obtained directly.

- Crimp points consist of a cutting phase of one or two sheets to assemble and a crimping phase for subduing materials.

The second class of points is different; there is no cutting of sheets to assemble. Two processes exist

- which are known by the names of their dies manufacturers: the BTM system with extensible dies, and the TOX system with fixed dies. In particular, the TOX process studied in this article, utilizes punch/die couples of cylindrical form whose die consists of a single part (pressing process with forming die) Fig. 1.

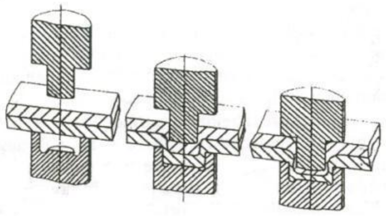

Fig. 1 Clinching process (TOX)

3. Simul

3.1 Governing Incremental Equilibrium Equation

The Updated Lagrangian formulation is used to describe large elasto-plastic deformation. The incremental virtual work equation for the time increment “t” to “t+Δt” referred to the configuration at “t” can be written in the following form

$$\int_{v}\left[\left(\sigma_{ij}^{J}-2\sigma_{ik}D_{kj}\right)\delta D_{ij}+\sigma_{jk}L_{ik}\delta L_{ij}\right]dv=\int_{s_f}\dot{f}_s\delta v_i ds \qquad (1)$$

3.2 Constitutive Equation

The J2 – flow constitutive equation

$$\sigma_{ij}^{J}=\frac{E}{1+\nu}\left[\delta_{ik}\delta_{jl}+\frac{\nu}{1-2\nu}\delta_{ij}\delta_{kl}-\frac{3\alpha\left(\frac{E}{1+\nu}\right)\sigma'_{ij}\sigma_{kl}}{2\bar{\sigma}^{2}\left(\frac{2}{3}H'+\frac{E}{1+\nu}\right)}\right]D_{kl} \qquad (2)$$

is employed to model the elasto – plastic behavior law of metals.

The equivalent stress – equivalent plastic strain relations are represented by a n – power law of t form

$$\bar{\sigma}=c\left(\varepsilon_0+\bar{\varepsilon}_p\right)^n \qquad (3)$$

Where:

$\bar{\sigma}_p$ is equivalent plastic strain

c, σ_0, n constant of behavior law of the metal

The integration of the elasto – plastic behavior law is realized with an algorithm of Simo and Taylor [17].

3.3 Finite Element Approximation

The spatial discretization of the incremental virtual work equation (1) and substitution of the constitutive equation (2), following the standard finite element procedure, yields a matrix equation of the form:

$$K\Delta U=\Delta F \qquad (4)$$

Where:

$$K=\sum_{e}^{NELT}\int_{V^e}\left[B^T\left(D_{ep}-F\right)B+E^T G E\right]dv \qquad (5)$$

In these equations:

denotes the nodal displacements increment ΔU

ΔF the nodal force incremental

K the global tangent stiffness matrix

D_{ep} the element elasto plastic constitute matrix

B the strain matrix

E the velocity gradient matrix

F and G the Cauchy strain matrix

$$[B]=\begin{bmatrix} a_i & 0 \\ c_i & 0 \\ 0 & b_i \\ b_i & a_i \end{bmatrix},\ [E]=\begin{bmatrix} a_i & 0 \\ c_i & 0 \\ 0 & b_i \\ b_i & 0 \\ 0 & a_i \end{bmatrix}$$

$$[F]=\begin{bmatrix} 2\sigma_r & 0 & 0 & \sigma_{rz} \\ & 2\sigma_\theta & 0 & 0 \\ sym. & & 2\sigma_z & 0 \\ & & & \frac{1}{2}\left(\sigma_r+\sigma_z\right) \end{bmatrix}$$

$$[G]=\begin{bmatrix} \sigma_r & 0 & 0 & \sigma_{rz} & 0 \\ & \sigma_\theta & 0 & 0 & 0 \\ & & \sigma_z & 0 & \sigma_{rz} \\ & sym. & & \sigma_z & 0 \\ & & & & \sigma_r \end{bmatrix}$$

With $a_i=\frac{\partial N_i}{\partial r}, \quad b_i=\frac{\partial N_i}{\partial z}, \quad c_i=\frac{N_i}{r}$

i=1,nnel (number of node per element).

N_i is the shape function of the node i.

4 Contact Modelling

Since the explicit time integration scheme is employed in the present calculation, it is essential that the contact and sliding states (contact, discontact, sticking and sliding) are kept unchanged within one incremental calculation step [18]. In order to satisfy this condition the r_minimum method [19][20] is utilized to limit the incremental step to such a size that;

- No free node comes into contact
- No contacting node starts to separate
- No sticking node comes to slide

in one incremental calculation step.

The solution procedure for r_minimum is as follows; a fictitious incremental displacement of the tool is prescribed at beginning of the step; the stiffness equation (4) is solved for the fictitious solution $\Delta \mathbf{U}$, the real incremental solution is determined by "rmin $\Delta \mathbf{U}$" in which the coefficient rmin is the smallest value of ratios r which are calculated based on several conditions [10][21].

5 Application

The preliminary tests of the computation code were concerned with the clinchage of two steel sheets ES 1.5 mm thick, achieved by means of TOX tools. The dimensions of tools are shown in Fig. (2). The sheets are discretized by 552 quadrilateral elements Q4 axisymetric with one – point reduced integration method and hourglass control [22]. Their contours are meshed by contact line elements. The friction between the tools and the sheets is supposed to follow Coulomb's law with a friction coefficient μ=0.1. The characteristics of the material taken into account are:

E=210000MPa, $\nu = 0.3$, $\sigma_y = 132.47$ MPa, c = 589 MPa, $\varepsilon_0 = 0.001$, n=0.216

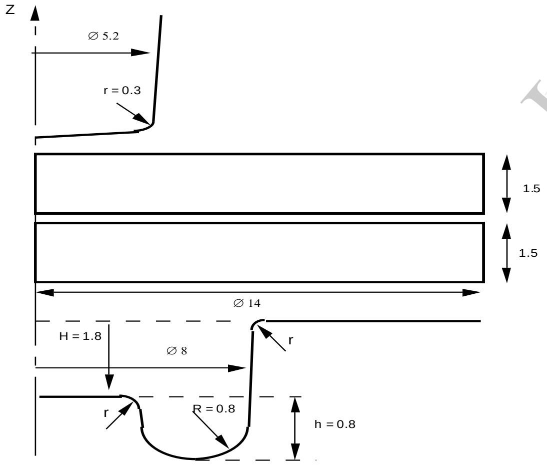

Fig. 2 Geometry of sheets and tools.

The grid generation is shown in Fig. 3.

The comparison of the load – displacement curves with experimental results is shown in Fig. 4.

The experimental values are slightly higher than the numerical ones up to a displacement of 3.5mm because of a possible difference between modeled and real mechanical behavior. The inflexion of the curves after a displacement of 2mm corresponds to the moment where the bottom sheet comes in contact with the bottom of the die. The experimental and numerical results are in good agreement.

The variations of the thickness in the sheets as a function of the curvilinear abscissa of the mean fiber are shown in Fig.s 5.

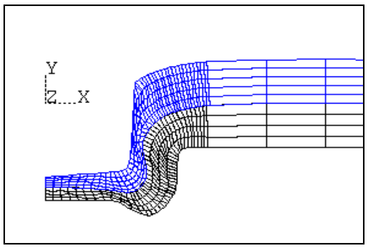

Fig 3 Grid generation

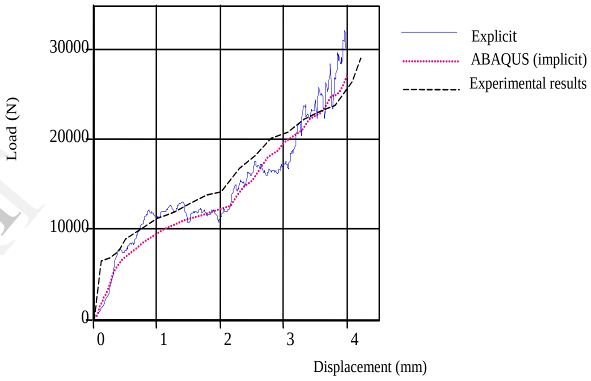

Fig 4 Load-displacement cuves

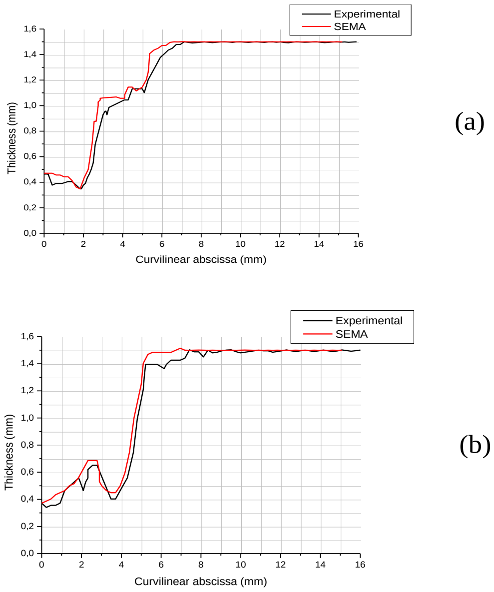

Fig. 5 Variation of the thickness:
(a) the lower sheet, (b) the upper sheet.

6 The Influence of Certain Parameters on The Process

Several parameters influence the clinch process in particular the behavior of material, the friction and the geometry of the used tools. The experimental study of their influence is difficult, to take a measurement specifies one needs numbers of significant tests. the numerical simulation can be a reliable and fast means to quantify the effect of the principal parameters of the process.

• The Influence of Friction

Friction is a significant parameter in the processes of working. In clinchage, the influence of friction on the variation thickness of sheets and the effort of working are remarkable, which are influencing automatically the final geometry of the point. Fig.s 6 and 7 show the influence of the friction coefficient on the variation thickness in sheets.

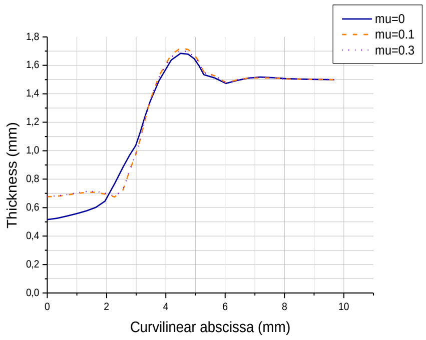

Fig. 6: Variation thickness of higher sheet for different coefficient of friction.

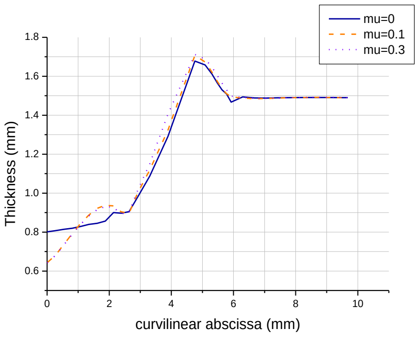

Fig. 7: Variation thickness of lower sheet for different coefficient of friction.

Fig.8 shows the effort evolution. At the beginning, we notice, that the evolution of the effort shows a regular increase according to the displacement of the punch. The evolution of the effort for a coefficient of null friction becomes to 40000N. On the other hand, we notice an increase in the effort until 50000N when the friction effect is taken into account.

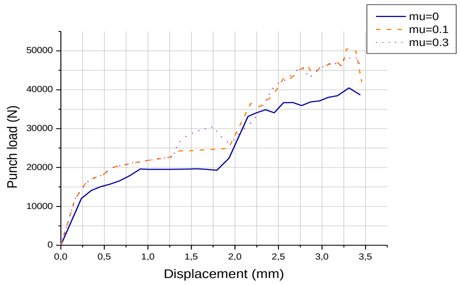

Fig. 8 Load- displacement curves for various coefficients of friction

• The Influence Of The Tools Geometry

The mechanical resistance of a clinch point is still based on the geometry of the used tools. Fig.s 9 and 10 show the influence of the diameter punch and depth of the matrix on the effort of the punch. On Fig. 9, we notice that the effort of the punch increases according to the increase in diameter punch. On the other hand, on the Fig. 10 the effort of the punch decreases according to the increase depth of the die.

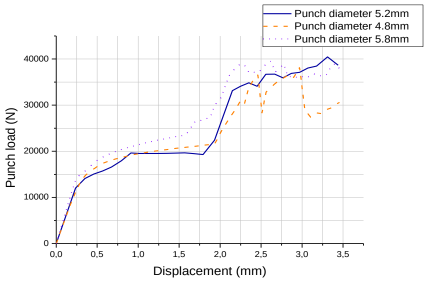

Fig. 9 Load-displacement curves for various diameters of the punch

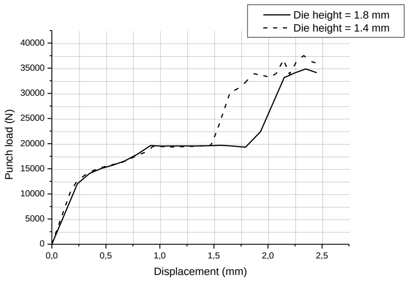

Fig. 10 Load-displacement curves for various depths of the die

7 Conclusion

The numerical simulation of the clinching by the static explicit method is reliable and rapid analysis method. The results obtained with the static explicit and the static implicit (ABAQUS) methods are in good agreement with experiment at a geometric level and the calculated evolution of the punching force is acceptable. The goal to study the clinching is based on the influence of some significant parameters such as the geometry of the tools and the friction. These mechanical or geometrical parameters influential on the result of the process are significant to ensure the best formation of the clinch point and its mechanical resistance. The future work will focus on the development of the computer code include the re-meshing and the introduction of damage variables to predict the clinching of the point and the service withstood and the application of the X-FEM.

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