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# NUMERICAL AND EXPERIMENTAL STUDY OF THE ERICHSEN TEST FOR METAL STAMPING

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**Abstract:**

In this article, we present some experimental results obtained from an ERICHSEN test. This test characterizes the faculty of the thin sheet stamping. In order to control the different parameters of this test, we make a confrontation between numerical results obtained with the finite elements software COSMOS/M and experimental results descended from tests realized on different material and thickness sheet metal

**Key Words:** ERICHSEN test, metal stamping, COSMOS/M software, strain, stress and displacement.

## 1. INTRODUCTION

The metal stamping is a forming process by plastic deformation of a metal surface carried by a punch in a die. The surface is transformed by molecular displacement of matter, with difficulty reversible; then we consider that the obtained piece is not developable. Besides, it consists to warp a thin sheet metal (blank) in a no developable surface. It is a technique fluently used in the industrial environment [1].

The operations of forming are often realized with mechanical or hydraulic presses and sometimes by processes using some particular energy sources as electric discharge in water, exploding or magnetic field.

## 2. DEFORMATION MODES

There are three different deformation modes depending on whether the blank-holder prevents or no the sheet metal sliding.

### 2.1. Stamping by expansion

If the sheet metal is blocked between the die and the blank-holder, the metal stamping is said by expansion. In this case, the sheet metal is elongated and machined down to follow the punch.

- The deformation is entirely resulted from a traction solicitation and intervenes under the punch whatever its shape ;
- The deformation is characterized by a machining down of the sheet metal.

### 2.2. Stamping by narrowing

On the contrary, if the blank-holder doesn't prevent the flowing of metal to supply the development of the piece, the metal stamping is said by narrowing.

- The deformation begins in compression traction and finishes in traction;
- It characterizes by a thickening of the piece partitions;
- The sheet metal is submitted to very complex stresses of tangent direction compression and radial direction traction (Fig. 1);
- The maximum of compression stress is situated toward the side;
- The maximum of traction stress is located in a zone near the radius of the stamped part.

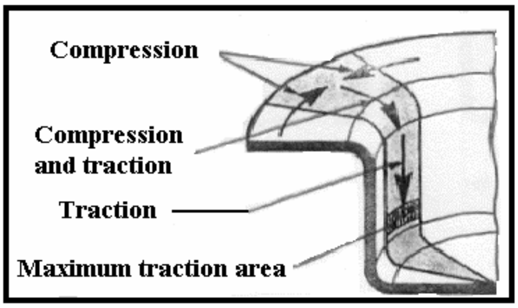


Figure 1: Analysis of the stamped sheet deformation.

### 2.3. Mixed stamping

In this deformation mode, the blank-holder brakes the sliding on all or on a part of its surface. For example, we can cite the method used for the metal stamping of coachwork pieces where, to permit a perfect tension on a particular zone of the piece, we brakes laterally the metal with rushes that oblige the metal to bend and to unfold with a component of friction.

## 3. DESCRIPTION OF THE ERICHSEN EXPANSION TEST

It is defined in the norms NF A 03-652, Euronorm 14-67 and ISO/R149. It is a sticking test of an hemispheric punch in a clamped blank on an open die (Fig. 2).

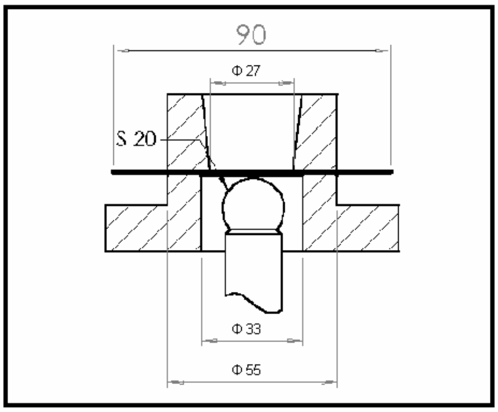


Figure 2: Erichsen test - schema and dimensions of the equipment.

The tool kit includes the following elements:

- A punch with a spherical or hemispherical polished head of diameter dp = 20 mm;
- A circular die of diameter dm = 27 mm with a rounded radius (vertical and horizontal partition adjusting) ρm = 0.74 mm;
- A squared test tube of side 90 mm taken in sheet metal of 0.5 to 2 mm of thickness.

The blank is clamped on the die by an effort of 10000 N. The punch and the two faces of the test-tube are lubricated by graphite grease. We measure the penetration of the punch at the moment where appears the first beginning of crack. This depth, expressed in millimetre, gives a number called Erichsen Indication that depends to the sheet metal thickness. The presence of friction in the contact of the sheet metal and the punch modifies the deformations distribution in the sheet metal that defers the one of an expansion test without friction. The result of the test (Fig. 3), depth of sticking at the moment where appears a beginning of crack [2], depends to some operative factors, firstly the friction conditions (lubricant and state of surfaces) and secondly the stop detecting (detection sensitivity of the crack beginning).

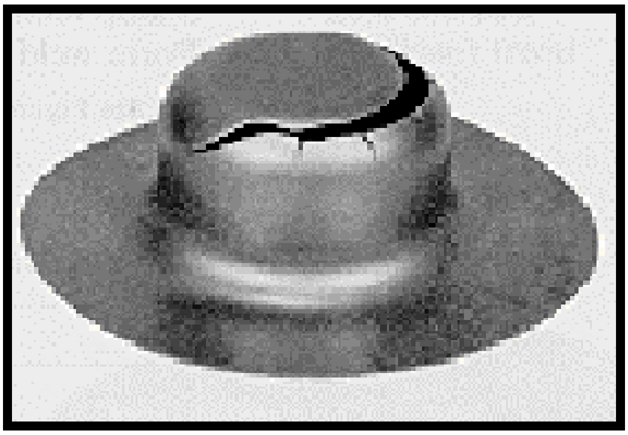

Figure 3: Test tube after attempt: the break localizes on a circle at a certain distance of the pole.

In order to get some comparable results between different laboratories, it is necessary to define in the detail the operative conditions (nature of the tool kit materials, toughness, roughness, lubricant, etc.).

For same family materials, for example the extra-soft steels, tried in the same conditions, we can find a correlation between the stamping part depth and the hardening coefficient n that characterizes the faculty to the expansion. When we consult a more extended range of materials, we find that this depth also depends, but in a least measure, of the anisotropy coefficient r that characterizes the faculty of metal to be thin on the punch.

## 4. MODELING OF THE ERICHSEN EXPANSION TEST

### 4.1. Simulation necessity

The control of the metal stamping became a reduction key factor of costs and delays in several industrial sectors, for example the car sector. Many simulation software (AutoForm, Isopunch, Optis, Pamstamp, Cosmos/M, ABAQUS, etc.) help engineers of studies and methods offices to finalize their tool kit of metal stamping. A simulation of a such process, that it is by an analytic method or by a finite element method [3], will be very useful for the understanding of the phenomenon and the control of its different technological parameters. With these performances, the finite element method [4] seems the most appropriate for the modeling of shaping processes.

### 4.2. Presentation of the software COSMOS/M

COSMOS/M is the software of simulation by finite elements [5], developed by SRAC (Structural Research and Analysis Corporation) for PC and workstation. The program includes modules to solve linear and nonlinear problems, static or dynamic, thermal problems, mechanical of fluids, electromagnetic and optimization. Analysis modules of special problems like the tiredness are also available.

GEOSTAR is the essential element meadow and post-processor of COSMOS/M, the GEOSTAR programs control the execution of several analysis modules of COSMOS/M and provide an interactive environment between them.

The essential stage in an analysis by finite elements can be presented as follows:

- Creation of the problem geometry;
- Definition of the model material properties;
- Creation of the definite geometry mesh;
- Application of the boundary conditions on the model;
- Definition of the model loading;
- Execution of the problem analysis;
- Interpretation and analysis of results.

### 4.3. Modeling description

The modeling by finite elements [6] consists to create the geometric model in order to be able to simulate its behaviour in a working context.

Our study consists to the simulation of the Erichsen test applied to different nuance sheet metal and thickness with the software COSMOS/M. This study will be realized in 2D axisymmetric with the revolute shape of the tool.

### 4.4. Modeling in 2D

#### 4.4.1. Creation of the problem geometry

Since we use the property of revolution (2D axisymmetric plane), all the elements must be defined in the plane X-Y, the axisymmetric structures are modeled in the positive half-plane X that represents the radial direction and Y indicates the symmetry axis [7]. At each node, we associate solely two degrees of liberty in the plane X-Y.

#### 4.4.2. Mesh of the structure

The theory of finite elements [8] can predict with precision the behaviour of every element under variable conditions. The whole of information concerning all elements of the model and the connections between them contribute to the behaviour prediction of the complete model.

The mesh is an important stage of the analysis, the size of the mesh generated (number of nodes and elements) depends to the geometry of the model and the size of specified element. In general, the choice of the element size influences on the precision of results.

In the software COSMOS/M, it is possible to create the surfaces mesh with two-dimensional elements, triangular or quadrilateral. Since in our study, we use the property 2D axi-symmetric plane, the suitable element is the quadrilateral element with 4 nodes or 8 nodes. In order to simplify the study (to reduce the number of nodes, the number of elements and therefore the number of equations), we chose the quadrilateral element with 4 nodes for the mesh of our model.

#### 4.4.3. Application of boundary conditions and loads on the model

The loading and the boundary conditions define the operative conditions for which our model is submitted at working.

Since we interest solely to modeling the elasto-plastic deformation of the sheet metal [9], and in order to simplify the study, we supposed that the system: die, blank and blank-holder is a rigid system stopped in displacement (6 degrees of freedom). On the basis of the punch, we imposed a displacement of 5 mm. The specification of loading and boundary condition can be before or after the mesh.

### 4.4.4. Application of contact on the model

The notion of contact is very useful in the study of linear and non linear problems. In fact, the contact permits to establish relations between the functional surfaces in a determined analysis.

The problem of contact can be presented with the following manner : at the origin, the contact is located in points i and j, then during the analysis the contact is located in points i' and k (Figure 4).

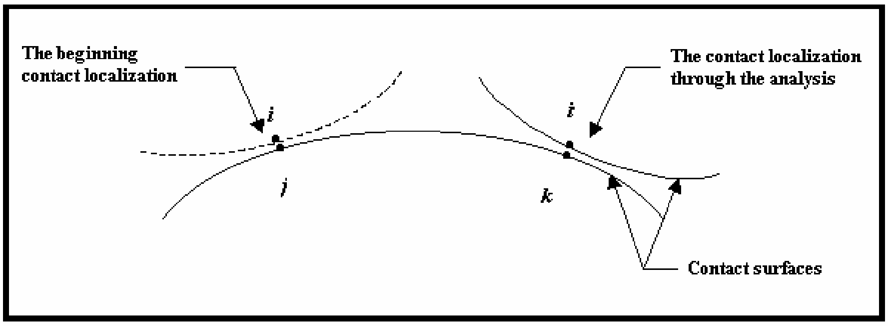


Figure 4: Problem of contact.

In our study, the establishment of contact is imperative in order to identify the relation between the lateral surfaces of the punch and the blank in the simulation in order to make the blank following the punch shape in the analysis.

### 4.4.5. Results and interpretations

Once the simulation finished, it is possible to visualize results under graphic and tabular format thanks to the period of incrementation already defined. As a rule, we are interested to five main characteristics:

- The distribution in deformed of the Von-Mises stress (Fig. 5);
- The distribution in deformed of the total strain (Fig. 6);
- The distribution in deformed of the displacement according to the axis (Oy) (Fig. 7);
- Curve of the (Oy) axis displacement according to the time (Fig. 8);
- Curve of the (Oy) axis displacement according to the reaction force (Fig. 9).

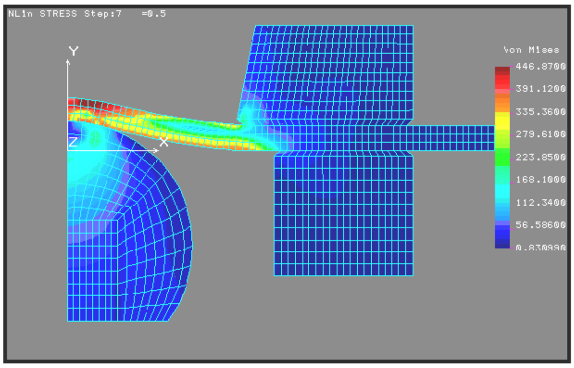


Figure 5: Distribution in deformed of the Von-Mises stress.

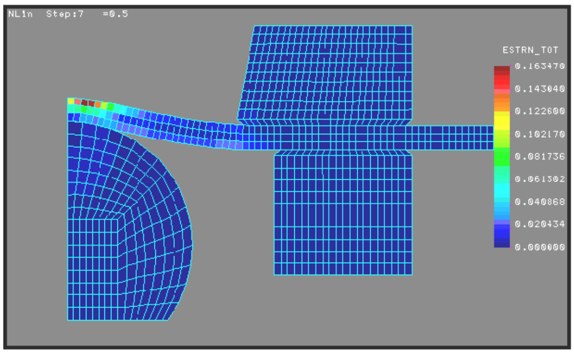


Figure 6: Distribution in deformed of the total strain.

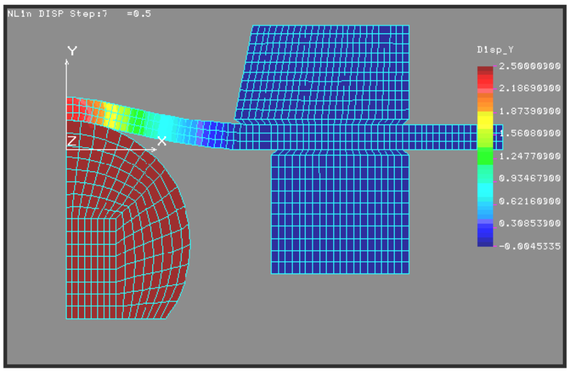


Figure 7: Distribution in deformed of the (Oy) axis displacement.

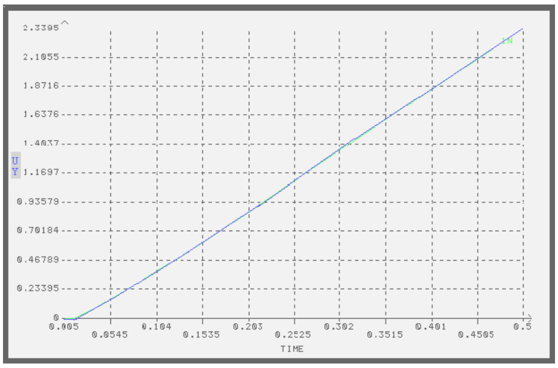


Figure 8: Curve of the (Oy) axis displacement according to the time.

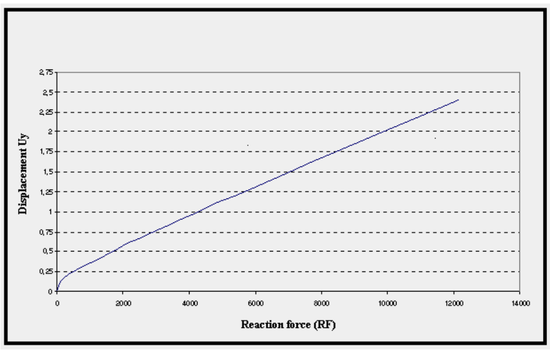


Figure 9: Curve of the (Oy) axis displacement according to the reaction force.

Figures 5, 6, 7, 8 and 9 represent the simulation results of a black sheet metal of thickness 2 mm.

The curve of distribution in deformed of the Von-Mises stress [10] describes the presence of a stress concentration in the sheet metal [11]. This concentration, situated in the superior part of the sheet metal, is due to the traction. On the other hand, the concentration located at the bottom part is due to the compression [12]. In return, the punch, the die and the blank-holder don't present stresses [13] concentrations since they are considered as rigid bodies.

The graph of distribution in deformed of the total strain describes the strain that undergo the sheet metal during the simulation. We notice that there is a localization of the total strain in the stamped part and in particular in its superior part, this localization is due to the concentration of stresses in this zone [14].

In the diagram of distribution in deformed of the displacement according to the axis (Oy), we represent displacements that undergo every element of the model, we are interested in particular to the displacement of the sheet metal, these displacements are variables, they describe the strains that undergo the blank.

The curve of the (Oy) axis displacement according to the time has a linear manner, that begins as soon as the sheet metal enters in contact with the punch, it shows that the penetration speed of the punch is constant during the simulation.

The curve of the displacement (Uy) according to the reaction force (RF) is linear, it shows that the force increases progressively with the penetration of the punch in blank. The increase of the force is due to the resistance of blank against the deformation until the moment where the force falls thanks to the apparition of the constriction phenomenon.

## 5. EXPERIMENTATION AND CONFR-ONTATION OF RESULTS

### 5.1. Erichsen test

Our study consists in realizing the Erichsen test on sheet metal of different materials and thickness in order to determine the effort Fc and the height IE of the stamped part generated just in the beginning of the apparition of the first beginning crack. It also consists to determine the effect of the lubrication on parameters of the test.

#### 5.1.1. Experimental device

The tests have been realized at the Laboratory of Physics and Materials Mechanical (LPMM) in the National School of Engineers of Sfax (Tunisia) on a testing bench (Fig. 10) formed by:

- A stamping tool for the Erichsen test;
- A traction machine working in compression mode and permitting the reading of forces. The measure of displacements is realized by a sensor.

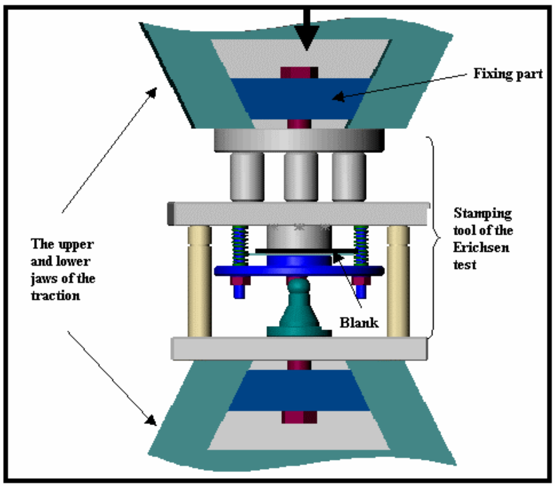


Figure 10: Experimental device.

### 5.1.2. Progress of the test

The different stages of the test progress are:

- Fixation of the tool on the traction machine;
- Regulating of the advance speed of the mobile jaw to 20 mm/mn in order to satisfy the conditions of the test;
- Making the tightening blank effort equal to 10 KN between the die and the blank-holder: this operation is necessary before every test. The calibration of this force is executed directly on the machine. We insert a cylindrical piece between the blank-holder, where the blank is putted, and the lower sole of the tool. Then, in compression mode, we reach a force of 10 KN displayed by the machine sensor, at this moment we tighten the three screws while preserving this constant force;
- Taking off the hold while going up the mobile jaw;
- Starting the test while following its progress on the mirror until the apparition of the first crack on the stamped part, we note at this moment the value of the breaking force Fc and we measure the displacement of the punch.

### 5.1.3. Results and interpretations

In Table 1, we have the different results of tests realized on the different types of sheet metal. In order to put in evidence the effect of lubrication, we realized two types of tests:

- Series of tests without using lubrication;
- Series of tests with lubrication: the used lubricant is a mineral oil.

Table I: Results of tests made on the different types of sheet metal.

| Nature of test | | .1.1.1.1.1.1.1 Non lubricated blank | | .1.1.1.1.1.1.2 Lubricated blank | |
|---|---|---|---|---|---|
| **Nuance** | **e (mm)** | **$F_c$ (N)** | **$I_E$ (mm)** | **$F_c$ (N)** | **$I_E$ (mm)** |
| **Aluminium sheet** | 1 | 2900 | 6 | 3200 | 6,4 |
| **Aluminium sheet** | 1,5 | 5900 | 8 | 6700 | 7,8 |
| **Galvanized sheet** | 1 | 13800 | 8,7 | 14400 | 9,4 |
| **Galvanized sheet** | 1,5 | 15200 | 11 | 14700 | 10,2 |
| **Copper sheet** | 1,5 | 30000 | 9,5 | 31800 | 11 |
| **Black sheet** | 1 | 10700 | 8,3 | 11300 | 8,9 |
| **Black sheet** | 2 | 34600 | 11 | 35200 | 10,8 |

From Table I, we drew curves showing the influence of:

- The nuance of the sheet metal;
- The thickness of the sheet metal;
- The conditions of lubrication on the Erichsen indication.

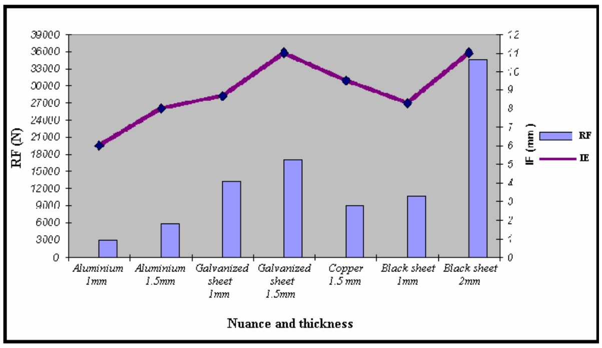


Figure 11: Variation of the Erichsen indication and the breaking force according to the material and the thickness of the sheet metal

We can conclude from Fig. 11 that, for one same nuance, the Erichsen indication and the breaking force vary in even direction that the thickness of the sheet metal. For a same thickness of sheet metal, we notice that IE varies according to the mechanical characteristics of the material (elastic limit); these results are confirmed by Fig. 12 representing the variation of the Erichsen indication according to the elastic limit of sheet metal studied. Therefore, the Erichsen indication depends on the elastoplastic behaviour of the material, the nuance and the thickness.

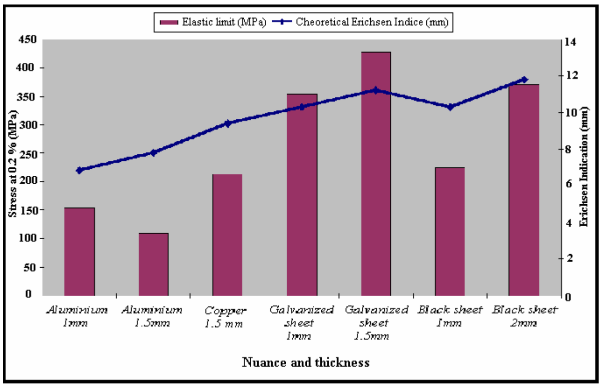


Figure 12: Variation of the Erichsen indication and the elastic limit according to the material and the thickness of the sheet metal.

Figure 13 shows us that the lubrication doesn't have any influence on the Erichsen indication and on the breaking force of the test-tube. Therefore, the use of the lubrication intervenes on the deformation mode of the stamped part in order to decrease frictions [15] on the active parts of the tool in and to increase their life duration.

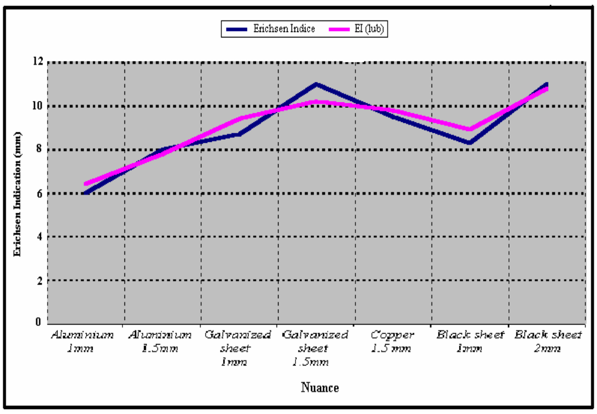


Figure 13: Influence conditions of lubrication on the Erichsen Indication.

### 5.2. Confrontation of measures of the metal stamping effort

After having realized the experimental tests on the different sheet metal, the found results are compared with those of the simulation for a stamped part displacement of 2 mm. This comparison is based on the metal stamping effort generating this deformation. Table II represents the different results.

Table II: Theoretical and experimental results of the stamping effort at 2 mm depth.

| Nuance and thickness | Practical effort at 2 mm (N) | Theoretical effort at 2 mm (N) |
|---|---|---|
| **Aluminium sheet 1 mm** | 1600 | 1720 |
| **Aluminium sheet 1,5 mm** | 2600 | 2580 |
| **Copper sheet 1,5 mm** | 4900 | 3900 |
| **Galvanized sheet 1 mm** | 3400 | 5292 |
| **Galvanized sheet 1,5 mm** | 9400 | 10100 |
| **Black sheet 1 mm** | 3400 | 2364 |
| **Black sheet 2 mm** | 10900 | 10000 |

## 5.3. Curves and interpretations

Fig. 14 represents a comparison between the theoretical and experimental metal stamping effort to 2 mm of stamped part depth for the different nuances and thickness of sheet metal.

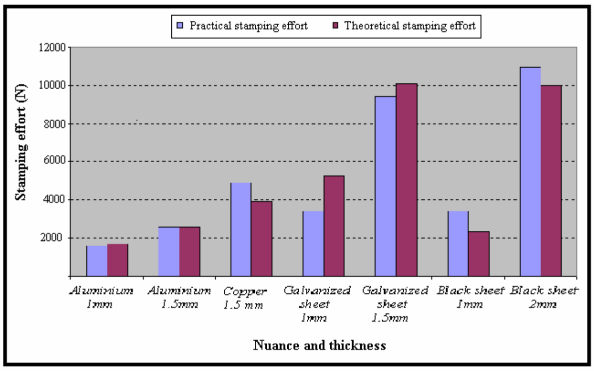


Figure 14: Comparison between the theoretical and experimental stamping effort at 2 mm depth.

We note that:

- The gap between the two results varies according to the nuance and the thickness;
- For a same nuance of the sheet metal, we notice that the simulation results are very near to those of the experimental;
- The gaps between the experimental and numerical results are due to the test conditions and mistakes of the simulation caused by the great approximations of the resolution method of elastoplastic behaviour laws.

## 5.4. Confrontation of Erichsen indication measures

The experimental Erichsen indication is measured during the realization of tests, but the theoretical Erichsen indication is determined from bibliography, they are presented in Table III.

Table III: Experimental and theoretical Erichsen Indication on the different types of sheet metal.

| Nuance and thickness | Practical Erichsen Indication (mm) | Theoretical Erichsen Indication (mm) |
|---|---|---|
| **Aluminium sheet 1 mm** | 6 | 6,85 |
| **Aluminium sheet 1,5 mm** | 8 | 7,8 |
| **Copper sheet 1,5 mm** | 9,5 | 9,39 |
| **Galvanized sheet 1 mm** | 8,7 | 10,3 |
| **Galvanized sheet 1,5 mm** | 11 | 11,2 |
| **Black sheet 1 mm** | 8,3 | 10,3 |
| **Black sheet 2 mm** | 11 | 11,8 |

Figure 15 represents a comparison between the theoretical and the experimental Erichsen indication for different nuances and thickness of sheet metal. We note a few differences that varies according to the nuance and the thickness, it is due to the experimental mistakes of measures and machine manipulation.

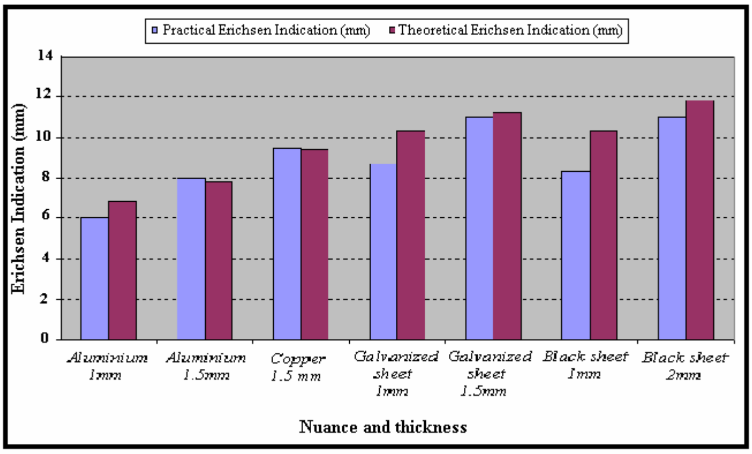


Figure 15: Comparison between the experimental and theoretical Erichsen Indication

The theoretical and experimental Erichsen indications are near for sheet metal of Aluminum and Copper. On the other hands, there is a few difference between the galvanized and black sheet metal, this difference is due to the correspondence made between the galvanized and black sheet metal and soft extra steel sheet metal.

## 6. CONCLUSION

Because the complexity and the high cost of the metal stamping process, the experimental tests cannot be pushed without material and technological limitations, therefore computer software is necessary to manage this technique and to control the metal stamping phenomenon.

The numeric modeling 2D axisymmetric realized with the finite elements software COSMOS/M is adapted to treat the ERICHSEN test metal stamping. In fact, the confrontation, between the numerical and experimental results obtained from tests realized on different sheet metal, shows an almost-perfect concordance in most cases.

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