

## Simulation of the Flattening of High Frequency Induction Welded Tubes

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The process of destructive and non-destructive testing of the manufacture of high frequency induction welded steel tubes has always give better results at the Labiod-tébessa Algeria tube construction plant such as tensile testing, folding, flaring and also the flattening tests whose limits of use were given by the experimental methods which have known deficiencies in measures in particular of the parameter of the height  $H$  which is given by the equation and that this difficulty is noted between the calculated and measured height levels. For these reasons it is necessary to find a numerical model of simulation which obviously replaces the experimental process to give reliable results with cheaper conditions in terms of cost and time which has been respected which allowed us to collect data. results and compare the different heights calculated and measure and often confirm the experimental tests.

*Keywords:* steel tubes, flattening, traction, removal, simulation, E24-2, H.

### 1. Introduction

The interest of this work of research is motivated by the concern to detect anomalies related to the welding (operation which consists in reuniting the constituent parts of an assembly, so as to ensure the continuity of the matter between these parts), and to scientifically analyze this problem in order to be able to propose solutions that ensure a quality seal.

The definition of the weld ability of these steels is complex because it is a qualitative property assessed using different criteria according to the envisaged achievements; it brings into play many parameters, steel being only one of them [1].

During the 1930s, broken bridges involved welded structures, particularly in Germany and Belgium, then during the second world war occurred in breaks Liberty Ships built using the welding technique. Later, other catastrophic ruptures affected pressure vessels [2].

Parts that break down in service lead to disasters such as that of Chernobyl [3]. One of the main applications of welding and the manufacture of tubes and other products made of aluminum or copper steel by a process that perfectly meets the industrial requirements is welding of tubes by high frequency induction (HF); this technique is now better known in Algeria and more precisely by the manufacture of tubes of different diameters at the plant of El-Abiod (Anabib) Tebessa Algeria.

Destructive tests such as: traction, hardness, resilience, flattening and flaring; Flaring by means of a frustoconical mandrel from the end of a specimen cut from a tube, until the maximum outside diameter of the thus flared tube reaches the value specified in the relevant product standard [4].

Folding presses, mainly used for V-folding, are directly derived from stamping presses [5].

But we chose as the basis of the flattening tests because it was used by Hannachi Med Tahar [6] in his doctoral thesis and taking the results found as references and finally to model this flattening experiment numerically and to observe the experimental results with the numerical simulation and to draw the appropriate consequences.

## 2. Experimental

the flattening of a specimen (between the trays of a machine), taken from the end of a tube or cut from a tube in the direction perpendicular to the longitudinal axis of this tube, continues until the distance between the trays measured under load in the direction of flattening reaches the value specified in the relevant product standard (see Fig. 1a and b); on the other hand in the case of flattening said block the inner surfaces of the test piece must come into contact with each other over at least half the width  $b$  of the flattened test piece (see Figure 1c). The machine used for this test must be capable of flattening the specimen at the height  $H$  prescribed between these two parallel and rigid planar plates. The width of the trays must exceed that of the specimen that is to say reach the month  $1.6D$ . The length of the test piece shall not be less than 10 mm and shall not exceed 100 mm. The test piece shall be considered satisfactory if no visible crack is detected without means of magnification; a slight cracking of the banks should not be considered as a reason for rejection [7].

Symbols and their designations are shown in the Tab. 1.

The flattening is conducted until the distance  $H$  (distance between plates, measured under load), reaches the upper limit value calculated by the following formula (1):

$$\left[ \frac{1 + K}{K + \frac{e}{D}} \right] e \quad (1)$$

E24-2: value of  $k = 0.09$  lower limit of  $H = 4e$ .

The results of the flattening test (for different diameters and thicknesses of the welded blanks) are grouped in the Tab. 2.

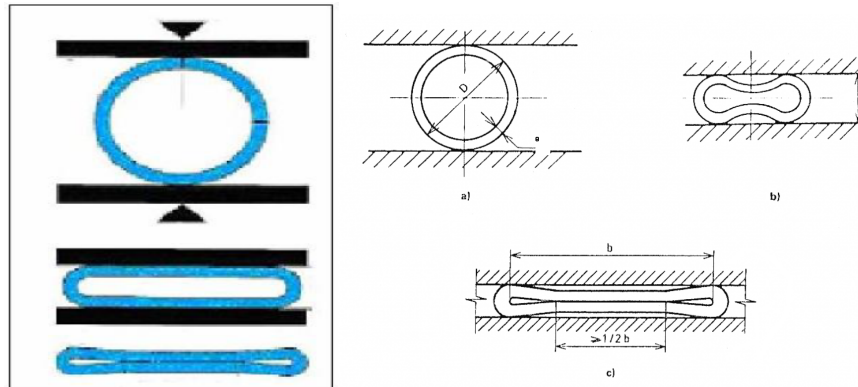


Figure 1 a, b and c: flattening test [7]

Table 1 Symbols and designations

Symbol	Description	Unit
D	Outside diameter of the tube	mm
e	the Wall thickness of the tube	mm
b	Internal width of the test piece flattened	mm
L	Length of the test piece	mm
H	Distance between plates measured under load	mm

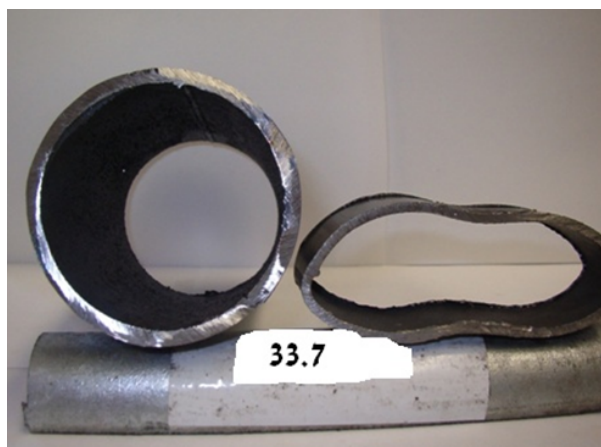
Table 2 Results of the flattening test carried on specimens welded blanks

N°	Dimension (mm)		Flattening		Observation
	D (mm)	e (mm)	H calcule (mm)	H mesures (mm)	
1	70.7	2.50	21.73	21.0	good
2	70.7	2.2	19.79	18.4	good
3	84	2.50	22.75	22.0	good
4	120.0	3.10	29.17	70.0	ruptur
5	110	2.50	24.17	30.80	Crack
6	114	2.50	24.34	54.0	ruptur

We have presented in Figure 2 test pieces that have undergone flattening.

The results of flattening (H) calculated and measured for different diameters and thicknesses in the case of finished products after annealing are summarized in Tab. 3. The values of (H measured) are measured directly in the laboratory immediately after each test, while those of (calculated H) and (H minimum) are given by formula (I) and Tables II and III, respectively.

As we have shown in Figures 3a, b and c, the variations of the flattening (H) as a function of the thicknesses (e) on the one hand, and as a function of the external diameters on the other hand, and this, respectively for test pieces: (finished product), after rolling and finally for blanks.



**Figure 2** Test specimens having undergone flattening

**Table 3** Results of flattening test carried out on finished products after annealing

N°	Dimension (mm)		Flattening		Observation
	D (mm)	e (mm)	H calcule (mm)	H measures (mm)	
1	40	2.5	18.11	19	good
2	40	2.2	16.53	17	good
3	33.7	2.2	15.44	15	good

We note from these curves that the values of (Hm) are slightly higher than those of (HC) especially for:  $e > 2.2$  mm (after rolling) and  $D > 33.7$  mm (finished product, on the other hand in the case of test pieces blanks (Fig. 3c.), the values of (Hm) and (HC) are almost the same for outside diameters at 70.7 mm, but for outside diameters below this value, the values of the Hm are greater than those of HC.

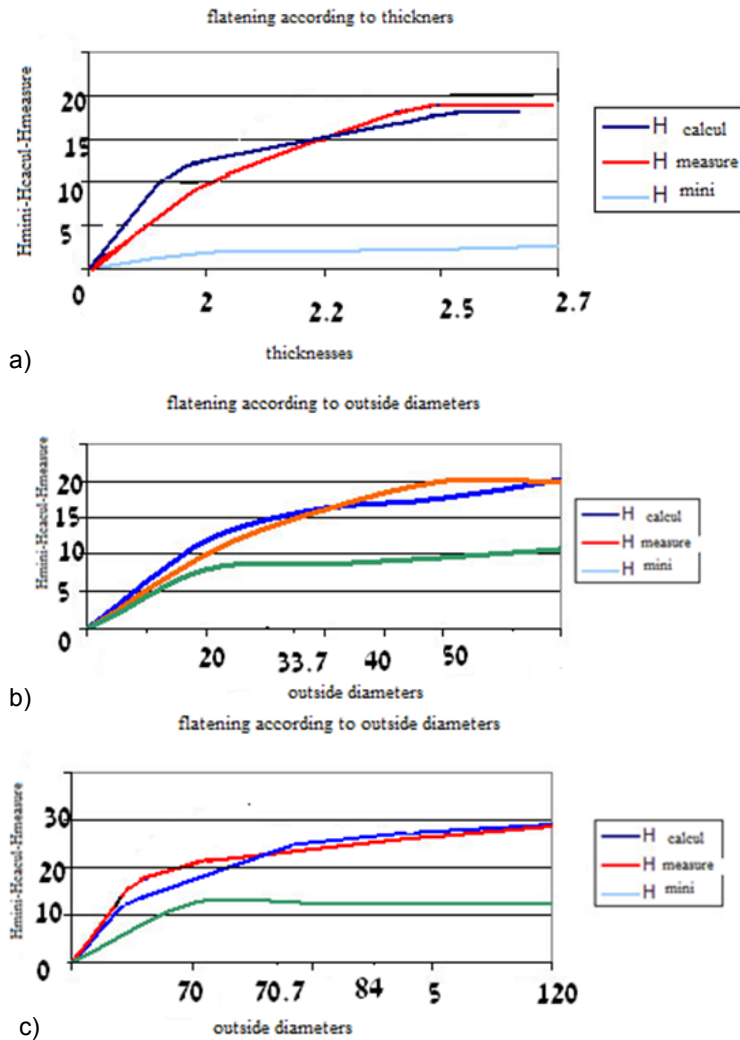
### 3. Modeling flattening

#### 3.1. Introduction

To better understand some of the process of induction welded pipe testing, we have tried to complete our work by a numerical simulation of the flattening of welded tubes by the finite element method using the castem 2001 software.

This numerical simulation devoted to the destructive control by flattening of these welded tubes presents different objectives:

- 1 – highlight the course of the test,
- 2 – understanding of the different phenomena involved in this flattening test,
- 3 – especially to describe the evolution of flattening (H) according to the loading.



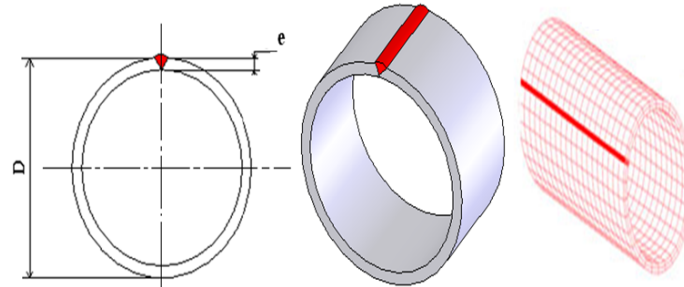
**Figure 3** a) comparison of the mini flattening calculated and measured in terms of the thicknesses after rolling and annealing [6], b) comparison of the mini flattening calculated and measured as function of the outer diameters for finished tubes [6], c) comparison of the mini flattening calculated and measured as function of external diameters for blanks tubes [6]

### 3.2. Dimension of the welded tube

The geometric features are shown in the Figure 4.

Cylinder of: outer diameter (D) ranging from 33.7 to 84 mm, thickness (e) taking both values: 2.2 and 2.5 mm.

And whose set of hardware parameters introduced in the simulation code are listed in the following Table 4.



**Figure 4** The geometric features

**Table 4** Characteristics of the material

Data	Value
Voluminal mass	$\gamma = 78,5 \text{ KN/m}^3$
Young's modulus	$E = 210 \text{ KN/mm}^2$
Poisson's ratio	$\nu = 0.3$
Elastic limit	$R_e = 240 \text{ MPa}$
Désignation	Structure

### 3.3. Numerical modeling

We will study and show on all the circle of the outside diameter cylinder (D) and thickness (e) during the flattening test the evolutions of H (flattening) as a function of the load. Then a comparison of the results of the flattening (H) will be made according to the thickness (e) and the outside diameter (D).

The assumptions used for the simulation are:

1. Building material E24-2.
2. Elastoplastic behavior.
3. In state of plane stress.
4. Explicit algorithm.

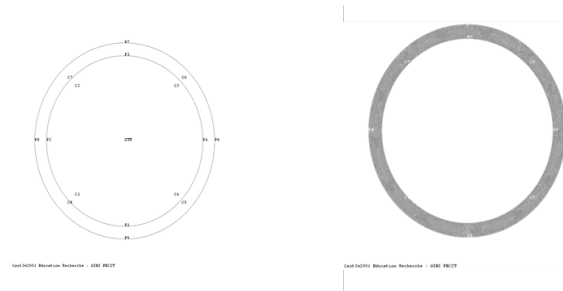
The cylinder is meshed with two-dimensional elements (triangles).

The object of this mesh is to geometrically discretize the domain of analysis so as to be able to associate a formulation finite element with the geometric support.

The use of the explicit method to solve elastoplasticity problems involves certain precautions; it is therefore a question of finding a compromise between the speed of calculation and the precision of the model.

### 3.4. Mesh geometry

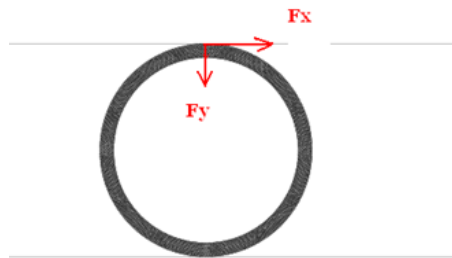
We presented on the Fig. 5a the numerical tools necessary for precise modeling in a mesh (Fig. 5b) of a section of welded cylindrical tube.



**Figure 5** a) tube sections modeled by Castem, b) mesh

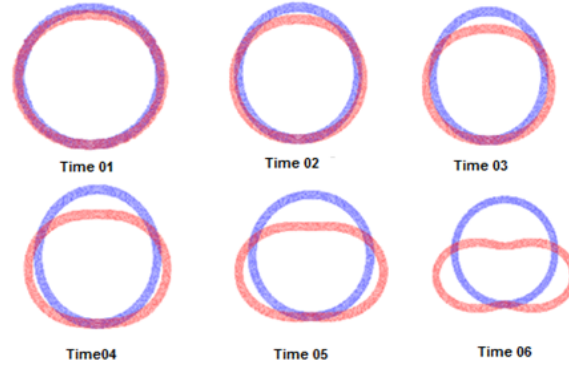
### 3.5. Loading applied

We applied a compressive loading ( $F = \text{variable}$ ) on the cylindrical tube while keeping the lower plate of the apparatus blocked (see Fig. 6).



**Figure 6** Components ( $F_x$ ,  $F_y$ ) of applied loading ( $F$ )

During the execution of the load and in a short time, the tube begins to deform by giving new structures (as shown in Figure 7) Such as: the oval and elliptical shape, this continues to reach the area of large deformations where the destruction and damage of the structure and the arcs of the circle begin to become parallel. Furthermore, the flattening of a tube of elliptical section has three distinct phases: first the tube is ovalized by canceling its curvature on the minor axis, then after



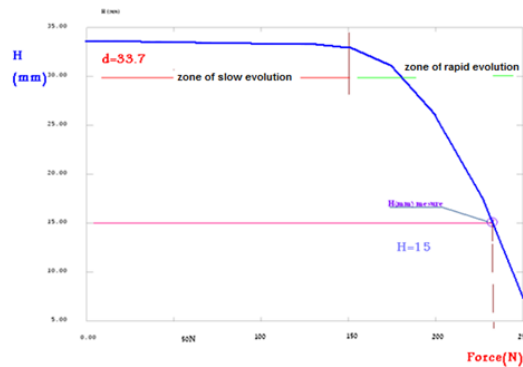
**Figure 7** Evolution of the flattening of the welded pipe section as a function of time

inversion of concavity, the opposite walls, which were substantially parallel, approaching to finally touch the center, and thus mark the beginning of the second phase. In this new phase, the curvature at the point of contact (center 0) becomes progressively zero; a contact segment can then develop in the last phase.

### 3.6. Flattening results ( $H$ )

The simulations are made with different geometrical dimensions of the cylinder ( $e = 2.2$  and  $2.5$  mm, diameter  $D = 33.7, 40, 70.7$  and  $84$  mm). We apply a progressive loading so that we can have all the values. This was found with the different simulations performed by taking for example the case:  $e = 2.2$  mm;  $D = 33.7$  mm. As for the curve of the Fig. 8. which represents the evolution of the flattening ( $H$ ) as a function of the load, and which is given directly and lastly by the Castem 2001 software, it consists of two parts:

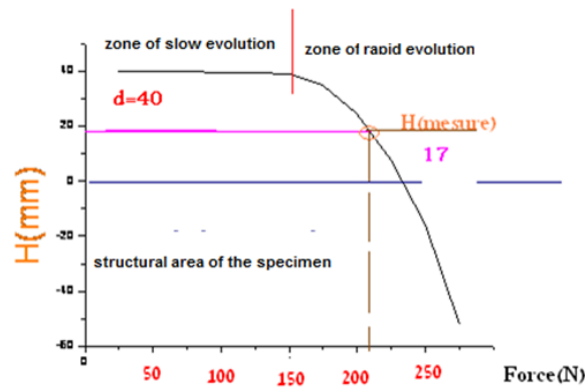
- a first part where the variation of  $H = f(F)$  is very small (stage)
- a second part where this variation becomes very important.



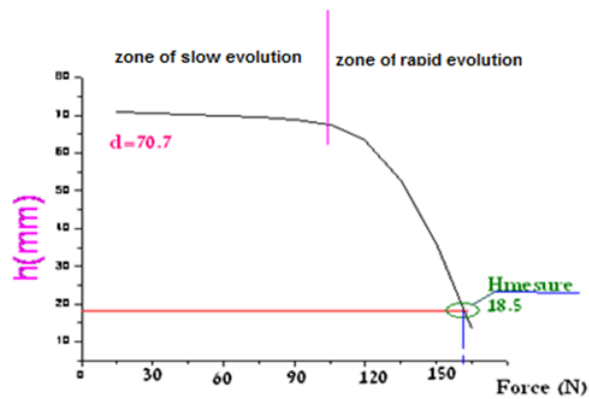
**Figure 8** Evolution of the flattening ( $H$ ) according to the loading (in the case:  $e = 2.2$  mm,  $D = 33.7$  mm)



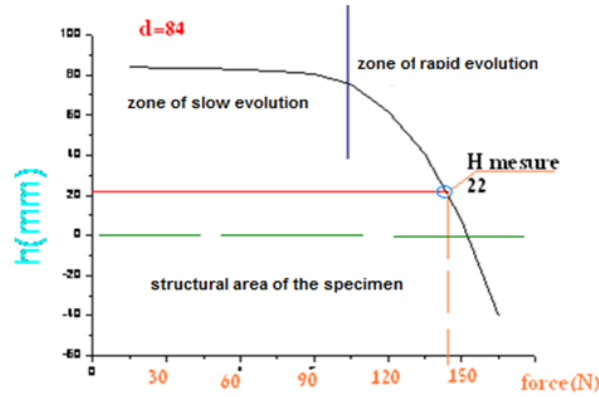
We have also noticed that the increase of the external diameters ( $D$ ) of the cylinder does not influence the shape of the curves of the flattening  $H = f(F)$ , represented on the figures 9, 10 and 11.



**Figure 9** Evolution of the flattening ( $H$ ) according to the loading  
(in the case:  $e = 2.2$  mm,  $D = 40$  mm)



**Figure 10** Evolution of the flattening ( $H$ ) according to the loading  
(in the case:  $e = 2.$  mm,  $D = 70.7$  mm)



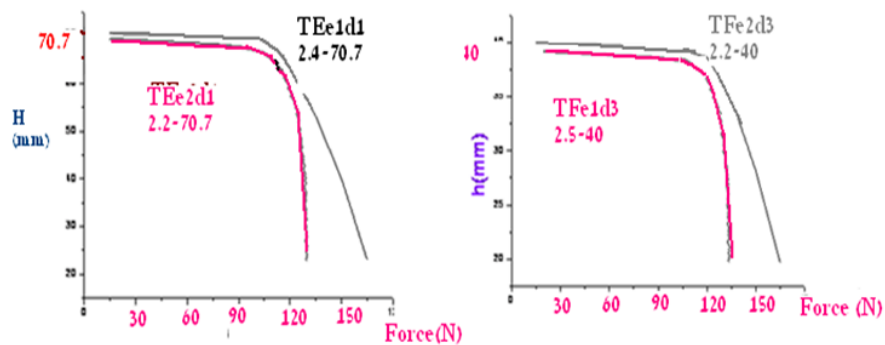
**Figure 11** Evolution of the flattening (H) according to the loading (in the case:  $e = 2.2$  mm,  $D = 80$  mm)

### 3.7. Interpretations of the results

Comparing the flattening curves  $H = f(F)$ , shown in Figure 12 we note that the variation of the thickness ( $e$ ) of the cylinder has a very great influence on the evolution of  $H$  and especially on the part of the curve which comes just after the stage: that is to say for  $e = 2.2$  mm, the evolution is very fast, on the other hand for a value of  $e = 2.5$  mm, this evolution is very slow, this can be explained by the presence of the plastic flow (more important in the second case).

Note also that this numerical method gives us information on the evolution of the flattening according to the loading without giving us the expected value of this flattening.

In other words, this software executes the entire program without stopping and gives us the final result directly: that is to say, the latter can neither detect the fault (crack initiation) nor stop, so the Hespere cannot be obtained.



**Figure 12** Comparison of flattening for different thicknesses Case of blanks and finished tubes

#### 4. Conclusion

The adaptability and reliability of the mechanical characteristics of the steel used (E24-2) goes through a series of quality controls by developing destructive tests (CD) mainly comprising: traction, hardness, resilience, flaring and flattening; the latter apply mainly to specimens (flat and sections of the tube), on blank (non-laminated welded tube) and on finished product (hot rolled tube and regenerated by normalization annealing).

However flaring, flattening, are tests that load axially, all these tests give the steel the appearance of being able to withstand higher stresses; the character Uniaxial of these tests actually limits their ability to detect certain types of weld problems. On the other hand, to better understand some processes of induction welded tube checks we have tried to complete our work by a numerical simulation of the flattening of welded tubes by the finite element method using the castem 2001 software, and this to understand the different phenomena involved in this test, and especially to describe the evolution of flattening (H) depending on the load.

From the results obtained, we can say that: the variation of the thickness (e) of the cylinder has a very great influence on the evolution of H and especially on the part of the curve which comes just after the landing: c for  $e = 2.2$  mm, the evolution is very fast, but for a value of  $e = 2.5$  mm, this evolution is very slow, this can be explained by the presence of the plastic flow (more important in the second case).

Note also that this numerical method gives us information on the evolution of the flattening according to the loading without giving us the expected value of this flattening.

To conclude we will say whatever the nature of industrial applications induction heating has a number of intrinsic advantages that explain its growing development. Accurate location of the thermal effect due to an inductor design and an operating frequency adapted to the room to be heated.

#### Acknowledgements

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