Proceedings of COBEM 2005
18th International Congress of Mechanical Engineering
November 6-11, 2005, Ouro Preto, MG

THE INFLUENCE OF THE FRICTION FACTOR ON THE TOTAL FORMING FORCE IN "T" METALLIC JUNCTIONS EMPLOYING ELASTOMERS

Cristiano Roberto Martins Foli
ITA – Aeronautic Technological Institute
Praça Mal. Eduardo Gomes, 50 – Vila das Acácias - S.J. Campos – CEP 1228-900
e-mail : foli@ita.br

Miguel Ängelo Menezes
Unesp – Sâo Paulo State University - Av. Brasil,56 – Centro Ilha Solteira - CEP 15385-000
e-mail : miguel@dem.feis.unesp.br

Lindolfo Araújo Moreira Filho
ITA – Aeronautic Technological Institute
Praça Mal. Eduardo Gomes, 50 – Vila das Acácias - S.J. Campos – CEP 1228-900
e-mail : lindolfo@ita.br

Abstract. *The using of elastomers for metal forming is one of the oldest processes for working this type of material. The main characteristic of the process is the great elastomer deformability under pressure; moreover, the friction developed between the elastomer and the metal can become a decisive factor in obtaining certain components. Among the forming processes employing elastomers stands out the forming of metallic junctions, where the main advantages of this process are low weight and high resistance of the product, besides the simplicity and the low cost of the tooling in process. One of important factors that influence the total forming force of metallic junctions employing elastomers is the friction making its measure a complex work, once it is not constant during the rehearsal due to the elevation of the hydrostatic pressure of the internal elastomer to the tube and the modification of superficial conditions of lubricating during the process. In this work is put forward an analysis of the influence of the friction factor on the total forming force in "T" metallic junctions, where the friction factor is not only dependent on the tube-die contact, but also on the elastomer-tube contact, mainly at the beginning of the forming process. For predicting of the total forming force, it was employed the upper-bound theory.*

Keywords*: Junctions Forming, Elastomers, Tube Forming, Friction and unconventional forming.*

1. Introduction

In spite of metal forming processes differ widely with respect to speed, temperature, and in the way by which forces are applied, all the processes possess a similar characteristic in terms of its physical parts of interest: tools under loading, plastic zones, interface between the material plastically deformed and the rigid tools, and also elastic-plastic transition regions in the material.

With the development of synthetic elastomers such as polyurethane, urethane and plastiprene, several papers were published using the elastomer metal forming technique, *e.g.*, deep-drawing of metal sheets (Al-Qureshi, 1972; Maslennikov, 1956), bending and piercing of tubes (Derweesh and Mellor, 1969; Al-Qureshi and Mellor, 1967; Al-Qureshi, 1971). Among the forming processes, stands out the forming of thin-walled tube junctions using elastomer (Marreco, 1979, Moreira Filho, 1985, Moreira Filho, 1998, Foli et al., 2003).

This last forming process presents a considerable number of variables, as for instance: the definition of the necessary relationship between the progress of the dome conformed and the developed pressure in the elastomer, the friction and lubricating conditions during the forming of junctions, the role of the anisotropy and the strain-hardening of materials, so as the influence of the strain-rate in the forming process and the definition of the maximum force to form the junctions.

Nowadays, the applications of tube forming technologies are continually expanding, especially in the automotive industries. The main advantages of the elastomer metal forming are, e.g. low weight and high stiffness of the product. On the other hand, in order to reduce weight of the component the wall thickness should be reduced. This is related with the increase of the friction, being that friction forces are responsible by the cross-section reduction during the forming process. As the contact pressure is high and the contact surface is large, the friction forces represent a dominant portion of the punch force. For that the friction coefficient should be measured, otherwise allowing the development of strategies for the reduction of the friction coefficient (Vollertsen and Plancak , 2002).

According to Fig. 1, there are two different kind of forming zones: the called feed zone and the forming zone. The feed zone is important to be a kind of reservoir for the material which is being pushed in to the forming zone. In the Fig. 2, the influence on the friction coefficient upon the contact pressure is shown.

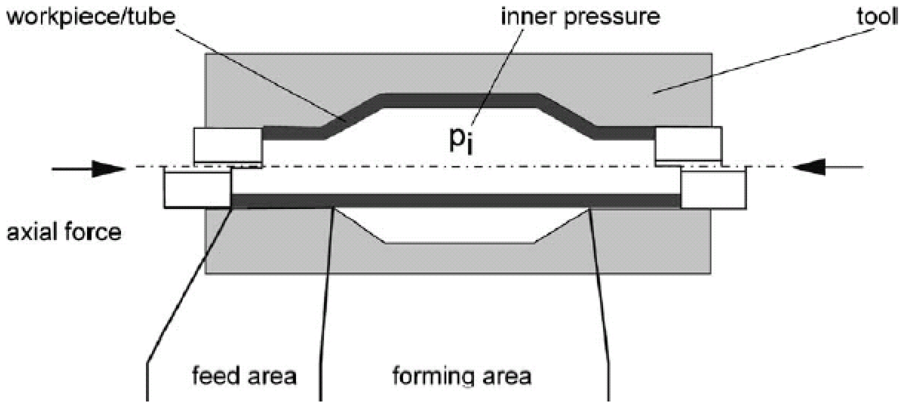


Figure 1 – Definition of different zones in forming, (Vollertsen and Plancak, 2002).

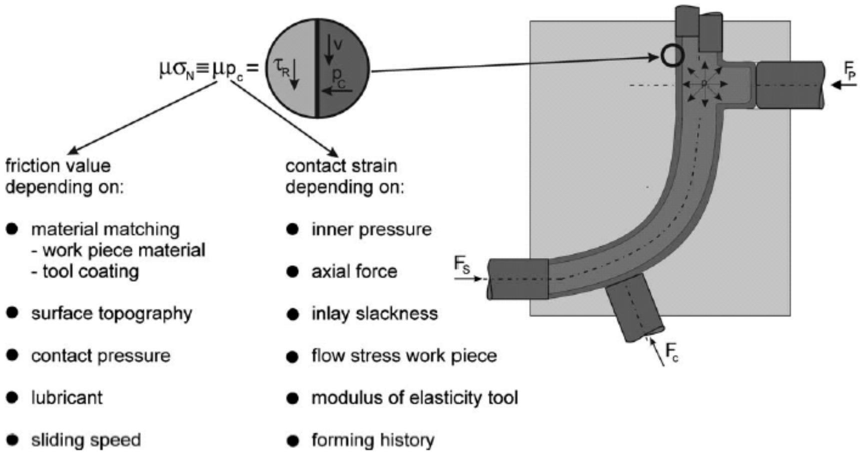


Figure 2 – Parameters that influence the friction in forming. (Vollertsen and Plancak, 2002).

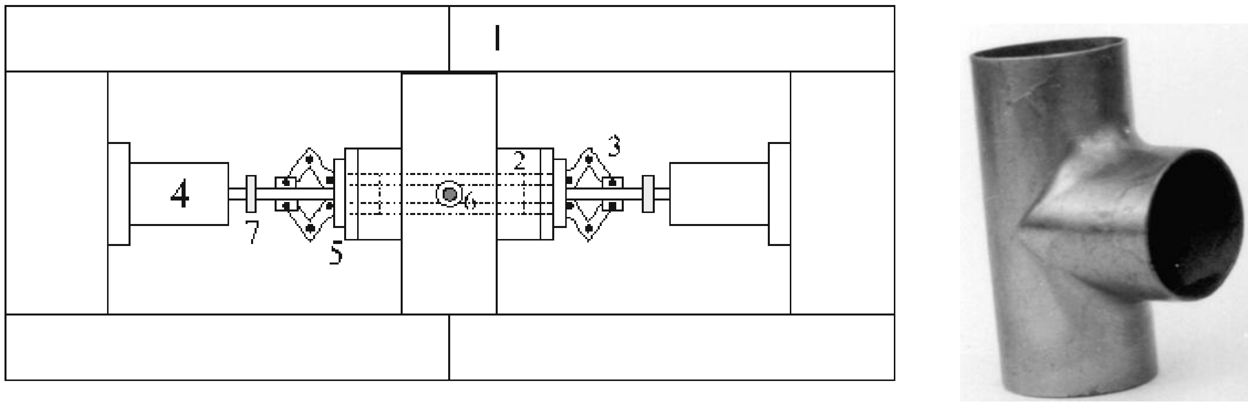
The friction exists in any metal forming processes. Whenever two solid surfaces are in contact and in relative motion, it arises a resistance (friction) to this motion. Friction is the last frontier in the study of metal plastic forming. For example, in the process of wire drawing, independent parameters such as reduction and die angle can be measured directly; however, friction can not be directly measured, it is not truly an independent parameter. For that, in many metal-forming processes, the friction effect is so important than the measuring of independent parameters (Avitzur, 1968).

In this work an investigation of the influence of the friction factor on the total forming force is proposed through the using of the elastomer for obtaining "T" junctions, in order to obtain a better agreement between experimental values and the analytical solution. For predicting of the total forming force, the upper-bound theory will be used. The employed materials for such investigation were Aluminum, Brass and Copper.

2. Experimental Procedure

A special forming machine was designed, built and automated in order to obtain a simultaneous loading on both tube ends. The equipment consists basically of a rigid frame structure shown in Fig. 3.a, with 30 tons capacity of hydraulic cylinders on both sides, activated simultaneously during the forming process. Fig. 3.b shows an example of a "T" junction obtained through this forming process.

The forming procedure consists, thus, in the gradual application of the load in the punch that initially produces solely compression in the elastomer; continuing the loading cycle, the second stage of the punch makes contact with the extremity of the tube, resulting in simultaneous axial compression in the elastomer and in the tube. In previous works, it was verified that the success of the operation, that is, the forming process without presenting fail by fracture or buckling, Fig. 4.a and 4.b, it depends on pressure applications, so in the elastomer as in the tube, in adequate proportion. It was possible through the control of the called "clearance height", that grows for each load cycle again and again.



1 - Machine frame
2 - Container
3 - Four-bar linkage
4 - Hidraulic Pump
5 - Punch-guide
6 - LVDT - domo progress measure device
7 - Load cell

(a) (b)

Figure 3. a) Schematic diagram of the tube machine. b) 'T'-junction.

(a) (b)

Figure 4. - Fail types in the tube forming. a) It fails for dome fracture b) It fails for local buckling.

3. Theoretical Model

According to the Upper Bound Theory, the existence of a cinematically admissible velocity fields is assumed such that the loads responsible by the formation of this field constitute an upper bound to the loads required for the real solution. The objective of this calculating is to obtain an estimating of the total forming force, and so to define the set of equipments necessary for the test. Figs. 5.a e 5.b, show the deforming geometry for the system.

The total force required was determined by the energy balance involved in the forming process, where the following energy portions that constitute this balance arise as:

$$\dot{W}_e = \dot{W}_i + \dot{W}_a + \dot{W}_b \qquad (1)$$

where,

$\dot{W}_e$ - External Energy Applied to the System;

$\dot{W}_i$ - Energy due to Internal Strain;

$\dot{W}_a$ - Energy due to Friction Losses; and

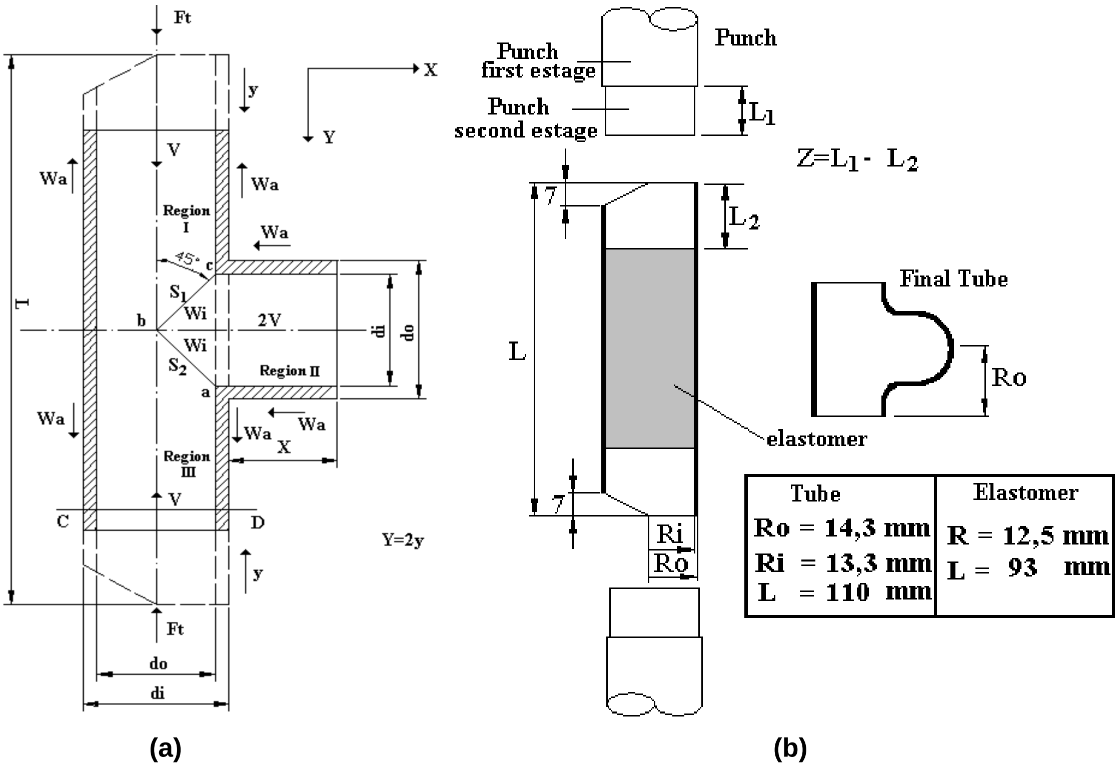
$\dot{W}_b$ = Energy Applied to the Elastomer.

The estimating of these energy portions leads to the formula presented for the total forming force, that was previously deduced in the reference, (Foli et. al, 2003), as follows:

$$F_T = \frac{\dfrac{\pi}{2\sqrt{3}}.\overline{\sigma}\left\{d_0^2 - d_i^2 + 2.m.(L - Y + X).d_0\right\} + A_0 E_C \left(\dfrac{d_i^2 - d_r^2}{d_r^2}\right) + \dfrac{A_i E^*.Y_3}{L'}}{2 - K.E^*} \qquad (2)$$

where:

F_T is the total forming force, $\overline{\sigma}$ is the yield stress, d_o and d_i are the outside and inside diameter of tube, m is the constant shear friction factor, Z is the initial tee length, Y is the total axial shortening of tube, X is the lateral penetration, A_0 is the initial area of elastomer, E_c initial elasticity modulus of elastomer, d_r is the diameter of elastomer, A_i is the internal area of tube, E^* is the theoretical elasticity modulus of elastomer, Y_3 ram movement due to displacement of elastomer, Z' is L-Y_1 (where Y_1 ram movement required to fill the elastomer/tube gap) and K is the volumetric compressibility.



(a) (b)

Figure 5. a) Velocity fields and Strain modes. b) Geometric parameters.

4. Results and Discussions

Analysing Eq. 2, one verifies that it depends on geometric factors, mechanical properties, operational conditions (dome progress) and the friction factor (m).

Due to the difficulty for determining previously the friction factor (m) during the process, a series of theoretical curves obtained using Eq. 2, fixing m and varying X up to X=do (maximum forming) were built in order to find an average value for the friction by comparing between theoretical and experimental values. So, it should be taken some cares; such as,

- uniform application of the lubricant along the outside surface of the tube and the inside wall of the die, with the purpose of minimising the friction variations; and
- the experimental process, it should be rigorously followed to avoid great variations for each rehearsed tube.

Examining Fig. 6, for the case of the aluminum is noticed an initial friction factor value of m=0.055. After that, it is observed that a friction factor m=0.05 stays practically constant up to the dome displacement point X=10 mm. It increases afterwards continually from 0.05 up to 0.08; value corresponding to X=d_o equivalent to the total forming. This variation can be explained by the fact that, as the process goes on, the lubricant between the external wall of the tube and the die loses efficiency due to its elimination, increasing more the contact metal/metal. Thus, through a pondered average between the experimental points and the theoretical curves, in Fig. 6, an average friction factor equal to 0.065 is calculated, which is useful in a preliminary evaluation of the total forming force for the aluminum.

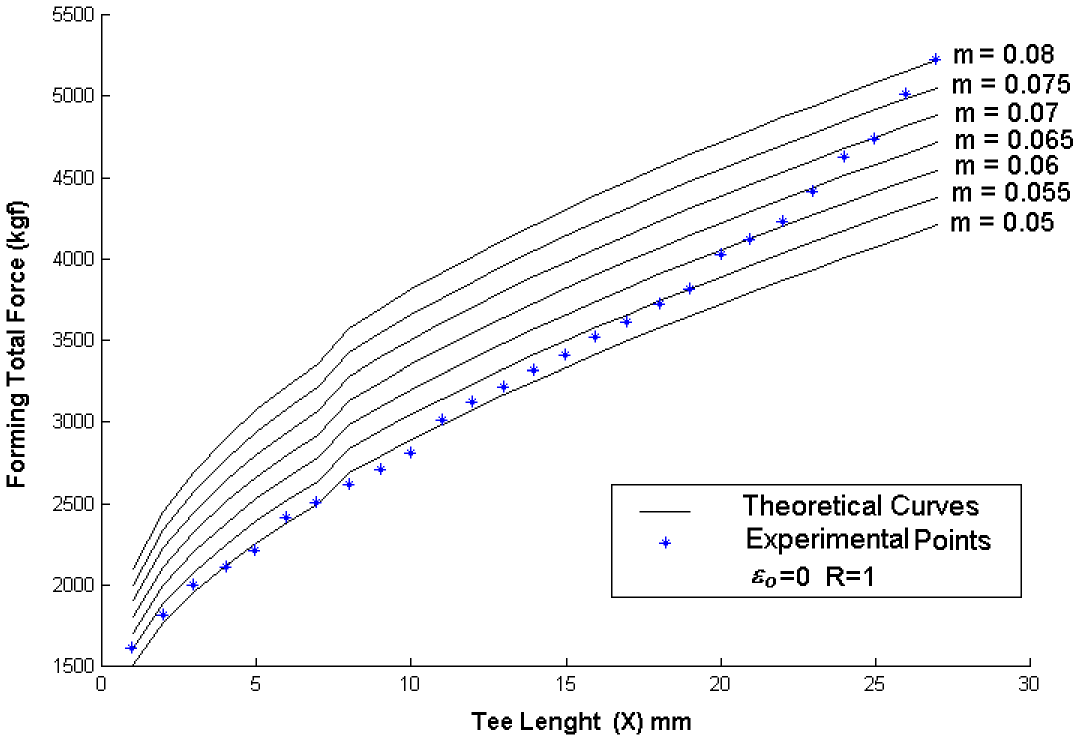


Figure 6 - Theoretical and experimental values of the total forming load - aluminum.

Differently, for the case of the brass in Fig.7 is obtained an initial friction factor value m=0.09, after that the friction factor stays constant (m=0.05) up to the dome displacement point X=10 mm. In this figure, it is observed yet that the friction factor variation m is quite larger starting from X=10 mm. From this point on it increases varying sigmoidally from 0.05 up to 0.10, value that corresponds to X=d_o equivalent to the total forming. The reason of the sigmoidal variation, in relation to that verified by the aluminum, it could be attributed to the condition of the final surface of the formed tube, where it was observed that such surface has presented the development of some roughness that certainly contributed to the increase of the friction among the tube/die surfaces. This development of the surface roughness can be attributed to the larger size grains of the brass tube in relation to the size grains of the aluminum tube, what led to larger deformation heterogeneity. This superficial effect is denominated orange peeling effect, which is characterised through a roughness visible. This problem can be amplified with that observed for the case of the aluminum (in this case, X≥20 mm), in that the lubricant film begins to lose your efficiency with the development of the process. So, through a new pondered average between the experimental points and the theoretical curves, in Fig. 7, an average friction factor equal to 0.07 is calculated, which is useful for a preliminary evaluation of the total forming force for the brass.

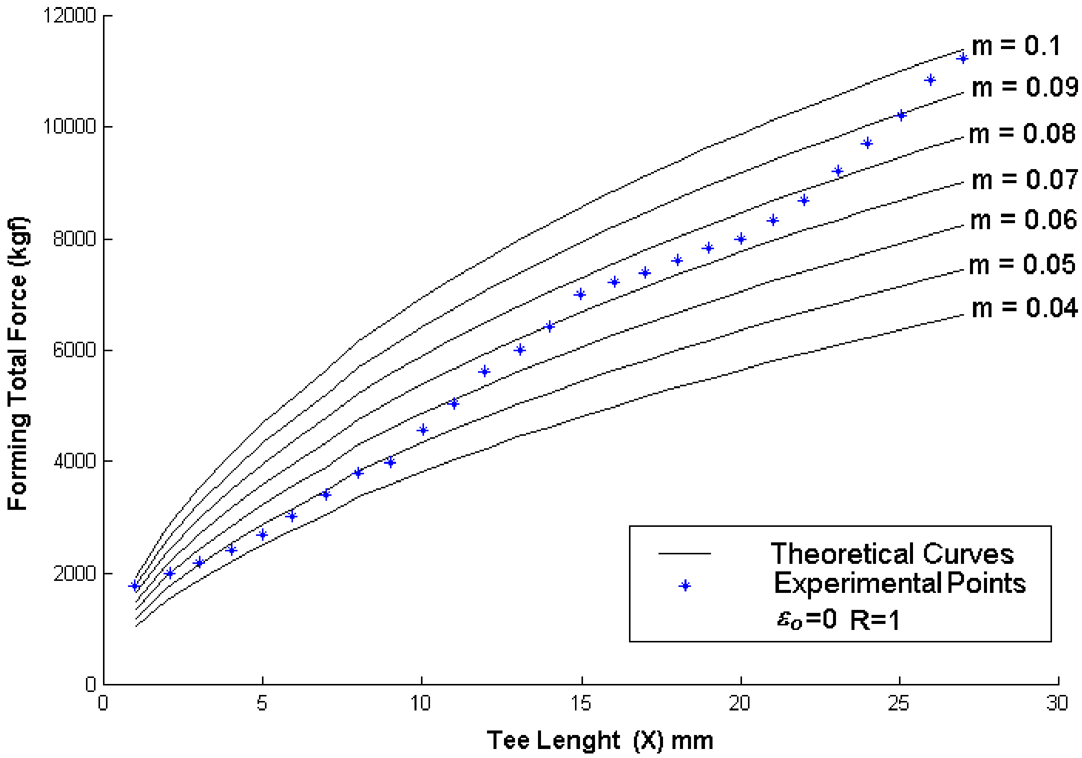


Figure 7 - Theoretical and experimental values of the total forming load – brass.

For the case of the copper, Fig. 8, it is noticed an initial friction factor value similar to that observed for the brass tube m=0.09. The fact of brass and copper tubes to present an initial friction value m=0.09, it is explained because both have strain-hardening indexes n values quite close, 0.57 and 0.45, and strength coefficients C, 79.0 kgf/mm^2 and 41.0 kgf/mm^2 respectively, for brass and copper tubes. In contrast, it was verified that although the aluminum tube with a strain-hardening index n=0.22 and strength coefficient equal to C=19.5 kgf/mm^2, it presented a friction factor m equal to 0.055, value that is lower than that found for brass and copper tubes. The difference in the friction factor at the beginning of the process, it can be accounted for considering the strain-hardening capacity and the strength coefficient values of materials of the rehearsed tubes. This because the die opening and the elastomer pressure, at the beginning of the process are the same ones for the three distinguish materials. Such difference should be attributed to the larger forming pressure necessary to push the brass and copper tube materials into the die entrance in relation to the aluminum tube. This larger pressure is translated by a larger total forming force, making the elastomer to push and to pull the tube material inside of the die opening. Hence, the friction factor, at the beginning of the process to be related to only the elastomer-tube contact, what explains the observed difference. In the sequence, the tube material starts to have contact with the die that makes the friction factor m to reduce a little its value (0.07 for the copper tube, and 0.05 for the case of aluminum and brass tubes).

Following the analysis for the case of the copper tube, the friction factor m=0.07, it stays constant up to the dome displacement X=10 mm. After a narrow variation in the friction factor is important to observe that between X>10 mm and X=d_o (total forming) there is no significant variation in the friction factor value m=0.08. This fact can be related to the smaller loss of the lubricant efficiency and explained by the excellent surface finishing of the copper tube when compared to aluminum and brass tubes. Besides, it can infer that the granulation of the copper tube would be more satisfactory in comparison with aluminum and brass tubes, because it did not present the orange peel defect in its surface. It is worthy mentioning that, close to X=d_o, the lubricant behavior was not already shown to be efficient, despite the best surface finishing of the copper, fact that was demonstrated by the sudden increasing in the friction factor value m in the end of the process.

As said previously, through a pondered average between the experimental points and the theoretical curves, in Fig. 8, an average friction factor equal to 0.075 is calculated, which is useful for a preliminary evaluation of the total forming force for the copper.

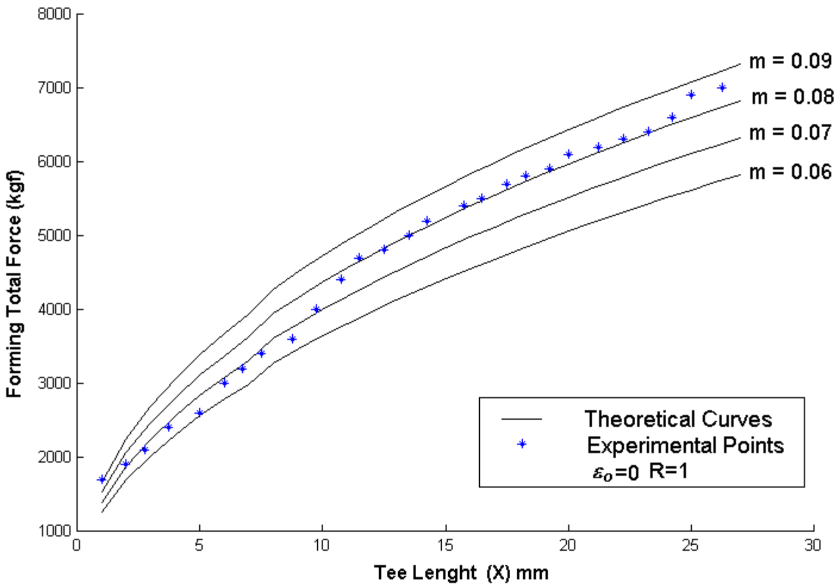


Figure 8 - Theoretical and experimental forming load values – copper.

5. Conclusions

Given the difficulty of doing a prediction of the friction factor *m*, an average value is used based on results obtained for three materials, aiming to do a first evaluation of the forming load. The average friction factor established for the aluminum is 0.065, for the brass is 0.07 and for the copper is 0.075.

The difference in the friction factor, at the beginning of the process, it can be explained taking into consideration the strain-hardening capacity and the strength coefficient value of materials of the three rehearsed tubes. This because in the die opening, the elastomer pressure at the beginning of the process are the same ones for the three different materials. Such difference should be attributed to the larger forming pressure necessary to push the brass and copper tube materials into the die entrance in relation to the aluminum tube. This larger pressure is translated by a larger total forming force, making the elastomer to push and to pull the tube material inside of the die opening. Hence, the friction factor, at the beginning of the process to be related only to the elastomer-tube contact, that explains the observed difference. This problem can be overlapped with that observed for the aluminum case, in which the lubricant film begins to lose its efficiency with the development of the process.

Acknowledgements: The authors would like to thank to the Brazilian National Research Council-CNPq, by the financial support and for funding the research.

6. References

AL-QUERESHI, H.A., 1972, " Machinery Prod. Eng". pp. 119-189.
AL-QUERESHI, H.A. and MELLOR, P.B., 1967, "Forming and Piercing of Metal Tubes with Polyretane", Eng. Material Desing 2".
AL-QUERESHI, H.A., 1971, "Factor Affecting the Strain Distributions on Thin-walled Tubes using Polyurethane Rod", Int.J.Mech-SCI, vol 13, p 403.
DERWEESH, F.L. and MELLOR, P.B., 1969, "Maslennikov's Technique for Forming a Cylindrical Cup", Proc. 10th Int. MTDR Conf.", pp. 499.
MASLENNIKOV, N.A., 1956, "Deep Drawing of Sheet Metal by Friction Forces", The Engineers Digest 17", pp. 366, Sept.
MARRECO, D.B., AL-QURESHI, H.A. ,1979b. Forming of T-Junction on Metal Tubes by Elastomer Rod Technique, Proc.7th North American Metal Working Researsh Conf., 13-19, pags 107-13.
MOREIRA FILHO, L.A., AL-QURESHI, H.A., 1985. Unconventional Tee Forming on Metal Tubes. Journal of Engineering for Industry, Nov.
MOREIRA, FILHO, L.A., 1998. "Modelagem Teórica e Automatização de Processo de Conformação de Junções em Tubos de Parede Fina". - Instituto Tecnológico de Aeronáutica, CTA., São José dos Campos, Tese de Doutorado.
FOLI, C. R.M, MOREIRA FILHO, L. A., MENEZES, M.A., 2003. "Alternative process for unconventional forming of junction in thin-walled metal tubes" In: Proceedings Of the 17th International Congress of Mechanical Engineering .v.1., 2003, São Paulo.
VOLLERTSEN, F., PLANCAK, M., 2002. "On possibilities for the determination of the coefficient of friction in hydroforming of tubes", Journal of Mat.Proc.Tech., pp 412-420.