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PREDICTION AND SIMULATION OF AXISYMMETRIC FORGING LOAD OF ALUMINUM

Nefissi N.; Bouaziz Z. & Zghal A.
Unit of Mechanics, Solids, Structures and Technological Development,
Ecole Supérieure des Sciences et Techniques,
BP 56 Beb Mnara 1008 Tunis, Tunisia
E-mails: nefissinaoufel@yahoo.fr; zobeir.bouaziz@enis.rnu.tn; ali.zghal@esstt.rnu.tn

Abstract:
The main objective of this study is to evaluate the load of forging process of aluminum assumed to be an isothermal steady state process using a reliable, fast and not expensive tool, contrary to the commercials software which require much means, time and a perfect knowledge of the process. In this study a developed data-processing tool based on slab method obtains estimation of forging load. It is shown that there is a good consistency between theoretical prediction and finite element simulation.

Key-Words: Slab method, Load prediction, Upsetting process.

1. INTRODUCTION

The development in forging technology has increased the range of shapes, sizes, and properties of the forged products enabling them to have various design and performance requirements. All forging companies are commercials concerns whose continued existence depends on their ability to make a profit. There are many ways by which this can be achieved, of which optimizing the preparation cost of estimate. In order to gain markets, these companies must be able to prepare a proper offer as well as the accepted offers represent only less than 10% of treated projects according to Techno*forg**. Increasing this percentage and reducing the preparation cost of the estimate represent a neuralgic field of research. Generally the forging industry such as Techno*forg*™ allot 50% of the total cost to the material, 20% to the tools and the rest to the operation of forging these two last are widely related to the required forging force. The constant raising of quality requirements and the continued globalization of the forging industry, represent the main driving force of research activities in cost estimation and simulation of billet evolution. The forging process has a large number of inputs each affecting the quality of the final part produced, the associated lead times and the energy used during the process. To handle industrial requirements, several methods are developed, we quote essentially the use of model-material such as lead and plasticine reproducing the industrial process with yield stresses' magnitude 500-1000 times lesser than of metals [1]. The finite element numerical analysis and simulation technology are the most often used expedient for simulating and prediction of different forging processes' parameters [2-3]. These computer methods give access to parameters, which are hardly given by experiments. The finite-element method (FEM) for elastic-plastic material property is considered to be an accurate method, but it is generally not very well suite for the severe material deformation typical in many metal forming process and can also result in long CPU time to carry out the computation. Upper bound technique is also widely used in analyzing the forging process [4]. There are two important parts that should be remembered about simulation codes. The first is no model however complex will be able to replicate precisely every phenomenon occurring in the forging operation. The second is that the user will only have a limited number of input parameters available to him.

These methods are broadly used in most forging manufactories despite the need of a perfect knowledge of the process, time consuming and a high cost of the estimates' preparation. The calculation of the required forging load is essential in the design of the forging process, in the determination of the preforms' number and in the selection of an appropriate forging machine. In general, the upsetting process can be classified as a forging process performed between two platens that can be flat, convex, concave, or any combinations of them in die surface shapes [5]. S.Y.Lin has studied the concave curve die for both the upper punch and the lower anvil, providing a symmetrical deformation mode. In this research work, an upset slab method of analysis for required forging load prediction has been studied. This method is used in most cases of analytic calculation of the press load in closed-die forging with flash [6]. An in-house calculation program was developed and used to determine the required upsetting force of a cylindrical billet performed between a combination of flat and convex dies shown in Fig.2. This leads to a reduction of the cost and time and to help specially small or medium size forge companies whose methods are essentially based on intuition, empirical guidelines and experience to get a cheap, sales tool.

The main structure of the developed code is explained in the following section. Afterwords, an example is treated. Then after demonstration of the accuracy of this code by a confrontation with a commercial software DEFORM^{TM}, the conclusion is drawn.

2. PRESENTATION OF THE ANALYTIC METHOD

Most empirical methods, summarized in terms of simple formulae or nomograms, are not sufficiently general to predict forging loads for a variety of parts and materials. Lacking a suitable empirical formula, one may use analytical techniques of varying degrees of complexity for calculating forging load and stresses. Among these techniques, the relatively simple slab method has been proven to be very practical predicting forging loads.

This analytic method has been established on the bases of a rigid-viscoplastic material implies that the flow stress is a function of strain, strain rate, and temperature and that the elastic response of the material is neglected. This assumption is very reasonable in analyzing metal forming problems, because the elastic portion of the deformation is negligible in most metal forging operations. Eighty percent of products are done in five processes of coining, drawing, extrusion, upsetting and piercing [7].

Our model is assumed to an upsetting process with a conic drawing end shown in Figure 1, consisted of the combination of two principal parts, one in simple flatness and the other is comparable with an axial conic drawing whose required load is the sum of both loads supposed to be independent processes.

The following main assumptions are made in the slab method analysis:

- The material is homogeneous, isotropic and incompressible;
- Elastic deformation and inertial effects are ignored;
- Only the external friction is considered in the analysis and the internal friction is neglected;
- The friction is constant:
- The metal flows based on the Von Mises rule.

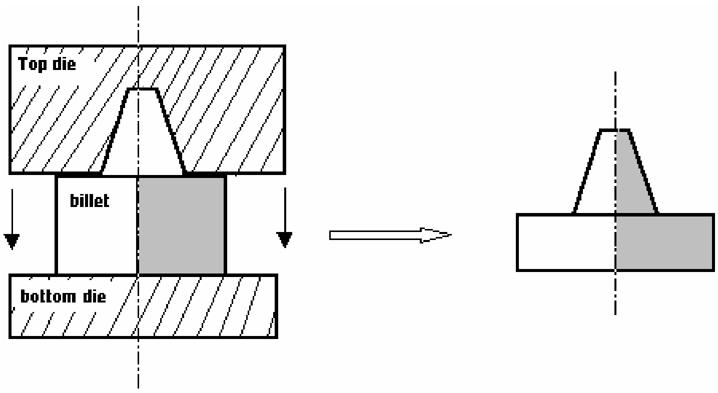

Figure 1: Proposed model.

3. DEFORMATION LOAD

The difficulty in solving such problems arises from the fact that plastic deformations require non-linear equations and these take such long time. Therefore, fast and accurate analytic solutions are suitable. The work piece is virtually divided into to parts as shown in Figure 2. This work piece is compressed along Y-direction between moving upper die with neglected velocity, as bottom die is held stationary. As deformation proceed thickness of the part (A) is shortened, while the part (B) elongates along Y-direction.

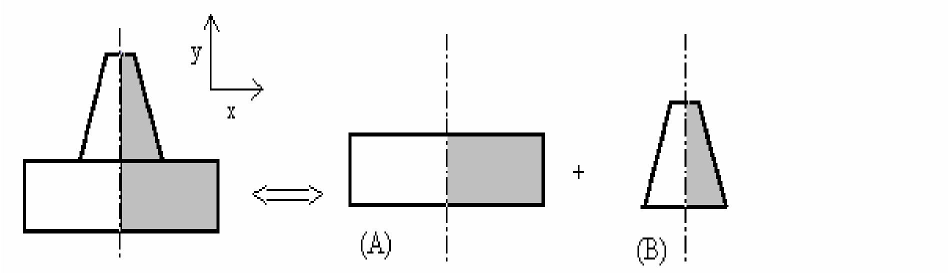

Figure 2: Subdivision of the work piece.

Due to the incompressibility condition, the volume constancy principle is imposed through all the process. The different characteristics of the work piece shape configuration shown in Figure 3 can be expressed by the following equations (1) and (2):

$$H_f = \sup \text{ of } \left(1{,}5.\ \frac{D_b}{D_0}(H_0 - H) \right)$$

and

$$\left((H_0 - H) + 0{,}34.H_0.\left(1{,}15.\frac{D_b}{D_0} - 1 \right) \right) \quad (1)$$

$$D = \sqrt{\frac{D_0^2.H_0 - \frac{1}{3}\left(.\frac{D_b^3}{2.tg\alpha} - .\frac{D_h^3}{2.tg\alpha} \right)}{H}} \quad (2)$$

where

$$D_h = D_b - 2.H_f.tg\alpha$$

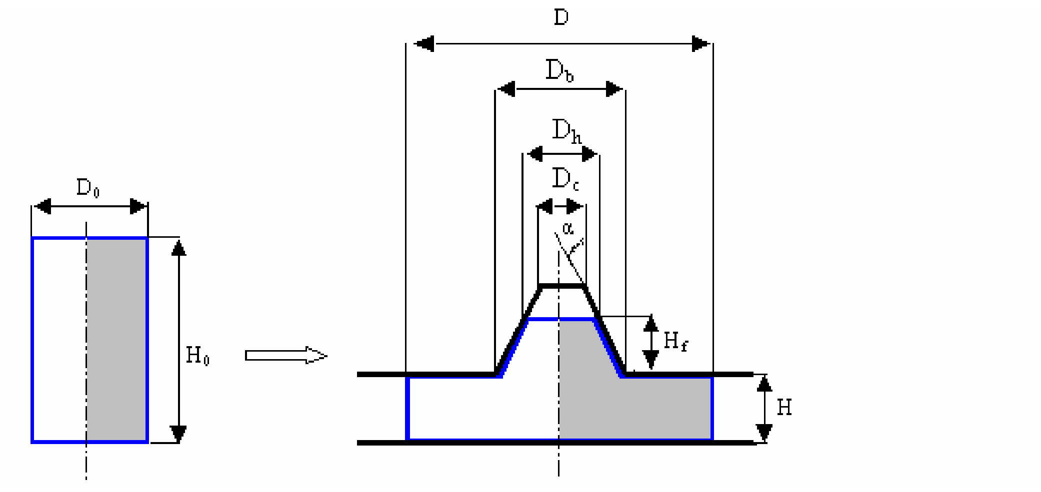

Figure 3: Work piece shape configuration (deformation in process until the upper die will be completely filled).

3.1 Load prediction

The top and bottom dies are assumed to be rigid. Part "A" is in a simple compression deformation and part "B" is in an axi-symetric upsetting deformation under inclined planes.

3.1.1 Part "A"

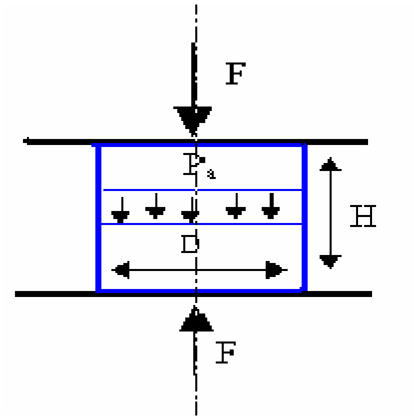

Figure 4: Part "A".

This part shown in Fig 4 is subjected to the efforts of compression given by the followed equation:

$$F = \frac{\pi D^2}{4} . \sigma(K) \qquad (3)$$

This function takes into account both the material and geometric characteristics while

$$K = \frac{H}{D}$$

and

$$\sigma(K) = \sigma_e \tau(K)$$

where σ_e represents the influence of the material and $\sigma_e = a + bT$

A and b are constant given as shown in Table (I) and T (°C) the temperature of forging

Table I: Identification of the laws $\sigma_e(T)$ [8].

Material	**a**(daN/mm^2)	**b**(daN/mm^2.°C)
Mild steel	223.1	-0.172
Aluminum-bronze	122.6	-0.126
Brass	104.0	-0.126
Copper	248.5	-0.246
AU4G	314.8	-0.550

Aluminum	79.0	-0.216

$\tau(K)$ represents the influence of the geometry.
Where $\tau(K) = 1{,}425$ if $K \geq 0{,}4$ unless

$$\tau(k) = \frac{1{,}44.10^{-6}}{K^5} - \frac{1{,}17.10^{-4}}{K^4} + \frac{4{,}08.10^{-3}}{K^3} - \frac{8{,}77.10^{-2}}{K^2} + \frac{1{,}65}{K} - 9{,}07 + 36{,}2.K - 68{,}2.K^2 + 51{,}89.K^3$$

This function was developed in polynomial form by P.Marin [9]; based on “universal” curve modelized by S.Tichkiewitch.

3.1.1 Part "B"

It is possible to calculate the forging load required for the part "B" shown is Figure 5 as a function of die stroke. Forces are developed by the reaction of the work piece (billet) with the die; these forces reach high values. The reaction of the billet with the die results in high compressive stress.

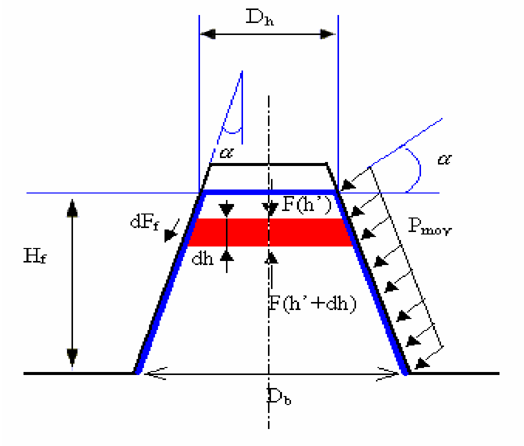

Figure 5: Equilibrium of the slab element in part "B".

The section considered is subjected:

- To the efforts of compression on the two faces:

$$F(h') = P_a(h') \cdot \frac{\pi (d(h'))^2}{4} \quad (4)$$

where P_a is the vertical pressure

$$F(h'+dh) = P_a(h'+dh). \frac{\pi (d(h'+dh))^2}{4} \quad (5)$$

- To the vertical components of the effort resulting from the pressure of the upper die:

$$dF_{P_r}(h') = P_{moy}(h').\pi.d(h').\sin(\alpha).dh \quad (6)$$

where P_{moy} is the average of pressure developed by the reaction of the work piece and the die and α is the semi-upper die angle

with $$P_{moy}(h') = \frac{P_r(h')}{\cos(\alpha)}$$

where $$P_r = \sigma(K)$$

- To the vertical components of the efforts of friction resulting from the pressure of the upper die:

$$dF_f(h') = P_{moy}(h').f.\pi.d(h').\cos(\alpha).dh \quad (7)$$

With *f* is the coefficient of friction of Coulomb in an extruded cavity.

The setting in equilibrium equation of the section leads us to the determination of the load necessary to complete the process:

For a quasi-static evolution, this section is in balance if:

$$F(h') + dF_{P_r}(h') + dF_f(h') = F(h'+dh) \quad (8)$$

the equations (6), (7) et (8) bring us to write that

$$F(h'+dh) - F(h') = P_{moy}(h').f.\pi.d(h').\cos(\alpha).dh + P_{moy}(h').\pi.d(h').\sin(\alpha).dh \quad (9)$$

by dividing the equation (8) by dh and replacing $F(h'+dh) - F(h')$ by $dF(h')$ we find:

$$\frac{dF(h')}{dh} = P_{moy}(h').f.\pi.d(h').\cos(\alpha) + P_{moy}(h').\pi.d(h').\sin(\alpha) \quad (10)$$

$$\text{with } d(h') = D_h + 2.h'.\tan(\alpha) \quad (11)$$

while replacing d(h') by its value of the equation (11) in the equation (10), equilibrium is written:

$$\frac{dF(h')}{dh} = P_{moy}(h').\pi.\left(D_h + 2.h'.\tan(\alpha)\right).\left(\sin(\alpha) + f.\cos(\alpha)\right) \quad (12)$$

The integration of the equation (12) on the height of the die filling H_f provides the total effort, by considering the limiting condition F(h'= 0) = 0 we find the necessary load is given as follows:

$$F_A = P_r.\pi(D_h.H_f + H_f^2.\tan(\alpha)).(\tan(\alpha) + f) \quad (13)$$

$$\text{while } D_h = D_b - 2.H_f.\tan(\alpha) \quad (14)$$

the equation (13) becomes:

$$F_A = P_r.\pi(D_b.H_f - H_f^2.\tan(\alpha)).(\tan(\alpha) + f) \quad (15)$$

We obtain the total load by adding equation (14) to equation (15) as follows

$$F_{total} = F_A + F_B = P_r.\pi(D_b.H_f - H_f^2.\tan(\alpha)).(\tan(\alpha) + f) + \frac{\pi D^2}{4}.\sigma(K) \quad (16)$$

4. RESULTS AND DISCUSSION

In order to validate the accuracy of the developed code Figure 6, the forging load was calculated for upsetting process and compared with that obtained by a finite element commercial software. To perform the FE simulation, DEFORM[TM] was employed. Since the axi-symmetric forging part (shown in Figure 1) has a vertical plane of symmetry, only half of its profile was modeled. An example is presented here to show the efficiency of the developed model. The geometry of the treated example is shown in Figure 7.

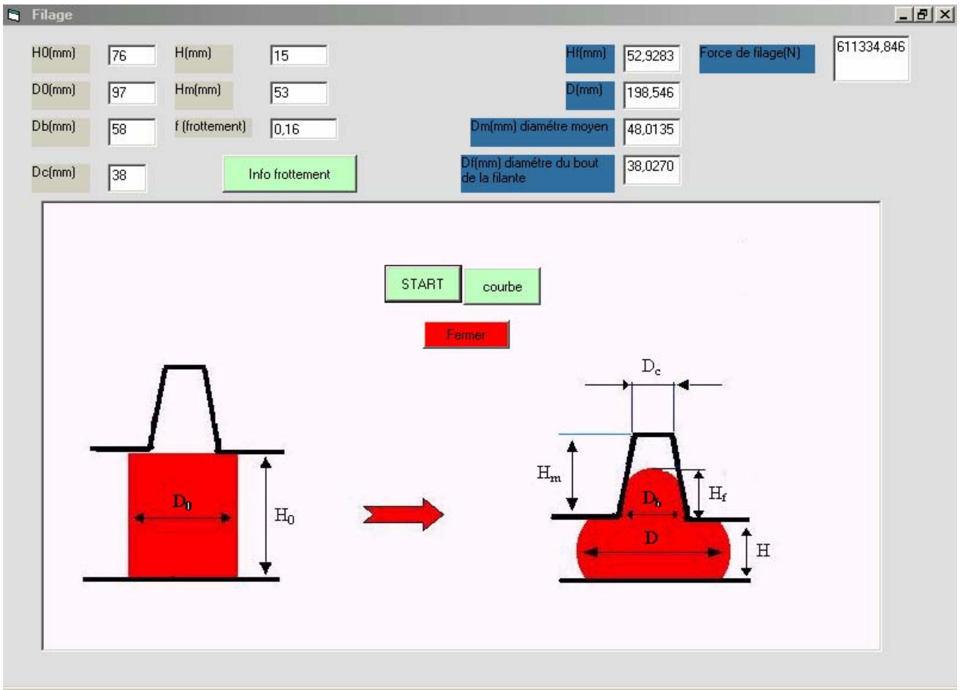

Figure 6: Developed code.

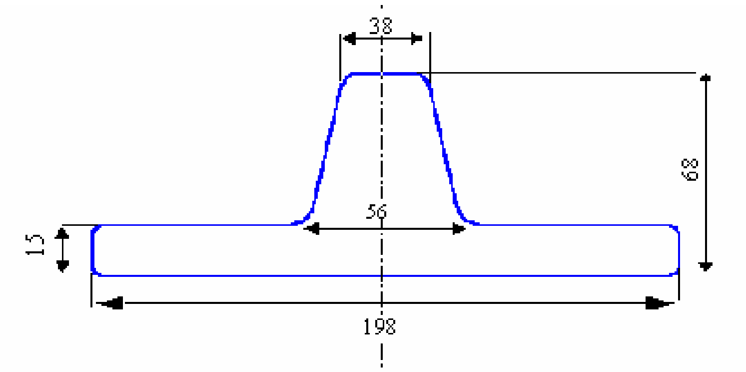

Figure 7: Dimensions of the forged part (mm).

The material for the simulation was chosen among those existing in Table (I) in order to create the possibility to investigate the model behaviour of aluminum in hot forging process (350^{o}C) with a constant coulomb frictional coefficient equal to 0,16. The first problem to be solved is the determination of the dimensions of the initial billet. So based on the hypotheses of the conservation of volume we can propose an infinity of possibility, with the developed code we can chose an optimal solution with a minimum load and energy by changing the initial billet dimensions as shown in Figure 8. This can be reached by imposing a simple geometrical condition, hence the final hauteur “H” of the part “A” must be reached at the same time when the upper die is completely filled as shown in Figure 9.

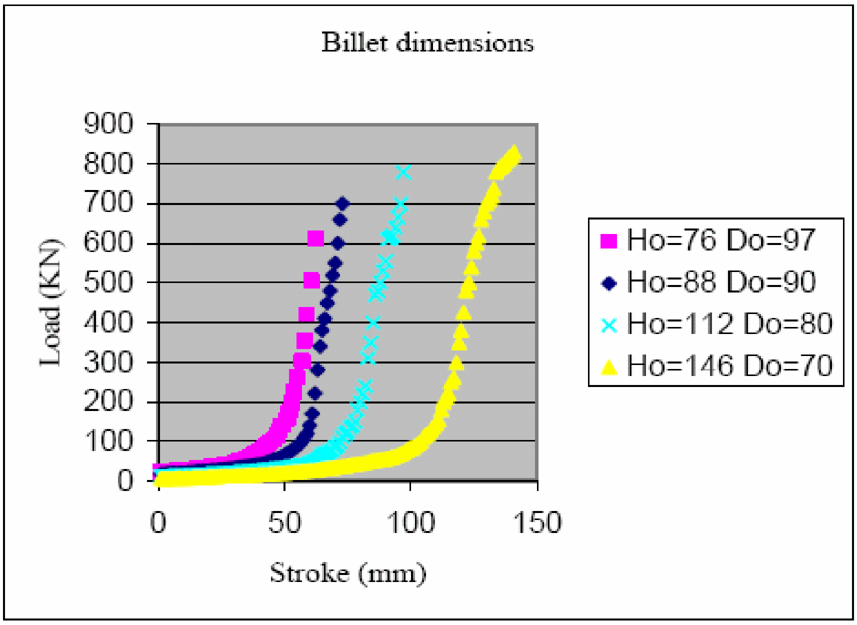

Figure 8: Billet dimensions.

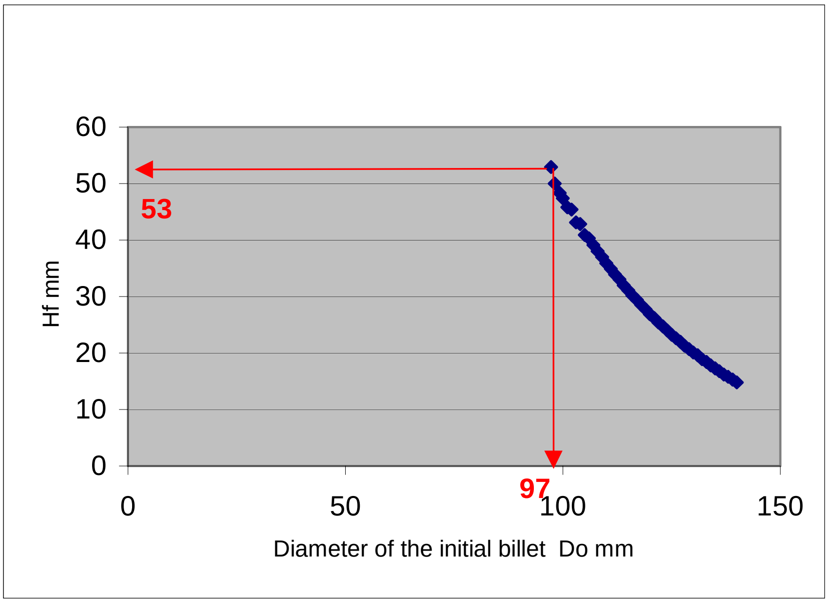

Figure 9: Variation of H_f related to the initial billet dimensions for a given hauteur H = 15mm.

The optimum dimensions for the minimum required load and energy are H_0 = 76mm and D_0 = 97mm.

Finite element software DEFORM^{TM} was used in simulating the process. Since the process is symmetric in nature, the 2D symmetric module was chosen. Aluminum-1100 was selected as the work piece material, and the friction factors at the interfaces between the tool and the work piece is governed by Coulomb friction law, with friction coefficient fixed to 0,16 throughout the hole simulation. The initial billet has dimensions of 97 mm in diameter and 76 mm in height and assumed to be rigid plastic while dies are rigid. To increase simulation productivity the automatic meshing and re-meshing procedure was chosen. Finally the temperature of the work piece is fixed to 350°C in an isothermal process performed with screw press-sample.

The stroke-load curves obtained by both the developed code and the commercial software DEFORM^{TM} have the same trend as shown in Fig.10. At the early deformation stage, there is only a small discrepancy between the theoretical prediction and the simulation result. However, the deviation becomes moderate as the degree of deformation is increased due to negligence of the barreling phenomena, which will accordingly result in the loss of some accuracy within the large deformation because the stress and strains under these conditions are no longer uniform [10-11] and the proper limits of the used method.

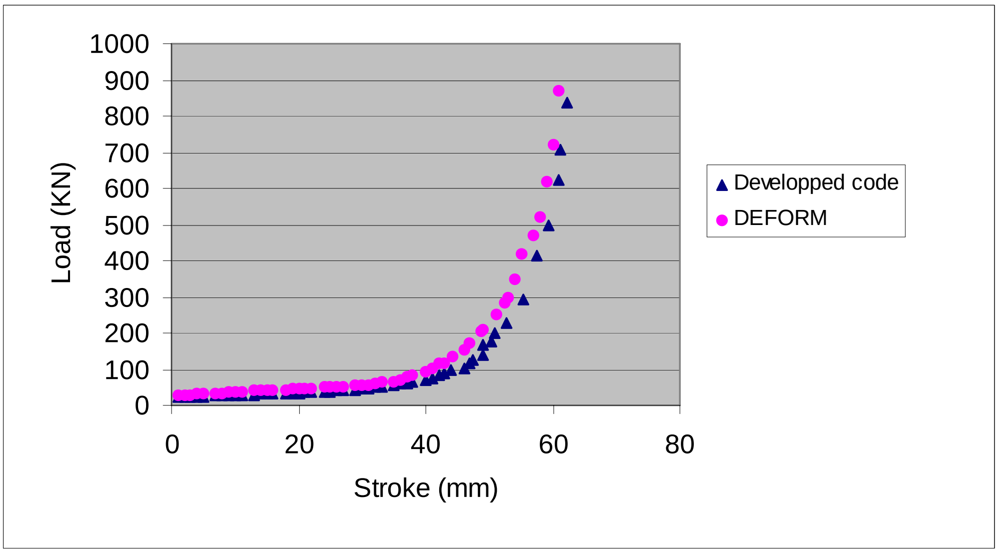

Figure 10: Simulated stroke-load curves.

5. CONCLUSION

An analytic model based on slab method has been developed to predict the load during hot forging (quasi-upsetting) of an aluminum work piece. Comparison between the results resulting from the developed code and the commercial software DEFORM^{TM} was performed to confirm the concordance of the developed code especially at the early deformation stage. More advanced approach for the complex shape and the integration of the barreling phenomena represent a vast field of research. This load can be easily transformed into energy making a solid base of cost estimation and used early in the stages of design in order to determine the number of pre-form according to machines' availability. Forevermore the forgers normally use the forging dimensions and weight estimated, required forging load and the speed at which energy will be imparted to the work piece to determine both the general type and the specific production unit which should be used.

7. ACKNOWLEDGMENTS

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